ENERAL ELECTRIC EDUCATIONAL PROJECTS

Electricity Lab

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GENERAL ELECTRIC
EDUCATIONAL PROJECTS

Electricity Lab

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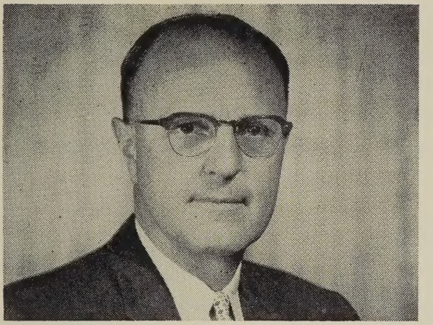


A Word of Introduction

By C. G. Suits

Vice President and Director of Research

General Electric Company

One may ask why General Electric has undertaken the manufacture of educational kits for young Americans. The answer is simple. High-quality kits that teach up-to-date science are urgently needed, because they provide a start on understanding the modern world and its technical wonders. Moreover, they may stimulate many bright young people to pursue careers in engineering or science.

No field offers youngsters greater promise of fruitful and useful careers than those of engineering and science. No task is more vital to the nation or to the world of tomorrow than encouraging the interest and understanding of young people in science. General Electric already has an extensive educational program aimed at these objectives, and additionally, at stimulating public understanding of science. It is entirely logical that General Electric should now bring its great scientific resources to bear on meeting the need for "learn-by-doing" kits, especially in electronics and related fields – fields in which General Electric has long been a leader.

Careful effort has been applied to make these kits conform to the standards of scientific quality synonymous with General Electric traditions. The focus is on the science of today, with its newest devices and components. For example, the electronic kits are built around the transistor, the little semiconductor element that is revolutionizing electronics. Modern scientific concepts of circuitry and performance are employed throughout the accompanying manuals. The kits are equally adapted to the activities of the youngster at home and to use in the schoolroom. They are both highly instructive and great fun to build – the very special kind of fun that comes from opening a door and discovering inside the beckoning world of science.

C. G. Suits

HOW TO USE THIS BOOK

To make it easier for you to perform the fascinating experiments possible with this kit and to understand the principle behind them, this manual is divided into the following nine parts:

PART 1 — What You Will Do with This Kit

PART 2 — How to Unpack Your Kit

PART 3 — Preparing Your Laboratory

PART 4 — Static Electricity

PART 5 — Introduction to Electric Circuits

PART 6 — Magnetism

PART 7 — Electrical Instruments

PART 8 — Advanced Projects

PART 9 — Suggestions for Further Reading

It is a good idea to look through the entire manual before setting up your laboratory. But be especially sure to read through Parts 2 and 3, "How to Unpack your Kit" and "Preparing Your Laboratory," before attempting to unpack your kit and do experiments. And be sure to read and follow carefully the instructions for each experiment you do.

PART 1

WHAT YOU WILL DO WITH THIS KIT

If you like to ask questions about everything under the sun, if you're the kind of boy or girl who always wants to know *why* and *how* — then this kit is meant for you. With it you will perform 25 experiments from which you will learn the most important basic facts about electricity and magnetism.

Here are some of the things you will build:

An electric motor, which you will also use to generate electricity;

Two kinds of code practice sets, which you can use for learning Morse code;

An instrument for measuring voltage;

An electroscope for studying static electricity.

And here are some of the things you will learn:

What electricity is;

Why a magnet attracts iron but not glass;

What alternating current is and why it is the commonest form of household electricity in the U. S.

The science you will learn from this kit will be modern, up-to-date science. When you are experimenting with electricity, you will learn that even though electric currents travel at fantastic speeds — 186,000 miles a second — the electrons that carry the current are usually traveling only a few inches an hour. When you experiment with magnets, you will find out the latest on an ancient mystery: why is a magnet a magnet? You will even meet a bit of Einstein's theory of relativity.

At the same time, you will find out how to assemble circuits and *work* with electricity and magnetism. Incidentally, these experiments in this kit are carried out with flashlight batteries, so there is no danger of electric shock.

You will learn enough so that you will be able to study other books — such as those liste on Page 50—and carry on experiments of your own. Also, your experience with this kit will be extremely helpful to you if you want to experiment with one of the General Electric electronics kits to learn about transistors and build a radio receiver or transmitter, an intercom, or an analog computer.

Thus you are going to learn a great many things that will help you to experiment at home, learn more in school, and understand many different things about what you see around you.

PART 2

HOW TO UNPACK YOUR KIT

Your Work Area

You will find working with your electricity lab easier if you choose a flat surface, such as a table, in a good light as your work area. Keep the trays your kit parts come in. They will be handy for storing parts when you are not working with them.

What You Will Need

Everything you need for working with your laboratory, including ready-to-use wires, is packed in the kit except for batteries and a number of comomn household articles. You should buy two D-size flashlight batteries. These are standard size flashlight batteries.

Opening the Kit

Hold onto the plastic see-through box top. It will be handy for protecting circuits you have assembled on your circuit board if you must put the kit away before you have finished an experiment.

When you removed the clear plastic top to get out this manual, you should have found a pair of plastic blister trays, one upside down and the other right side up, with a plastic insert sheet between them. *Fig. No. 1* shows how to disassemble them. Keep the plastic insert sheet as well as the trays. Beneath the blister trays are a plastic bag, containing parts for the electroscope, and additional parts.

In the upper tray, you will find two plastic bags containing the parts for assembling a bell and a motor. Set them aside without opening them until you are ready to use them.

You will soon need the parts in the bag in the bottom of the box. Open it and empty it into the blister in which the bell kit was packed.

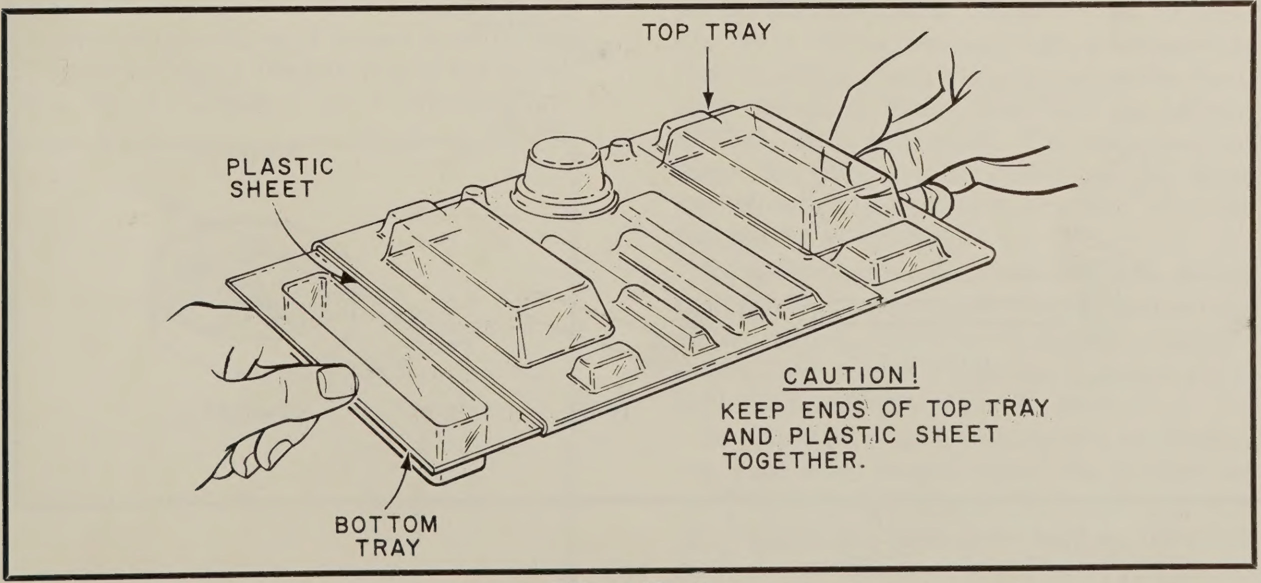
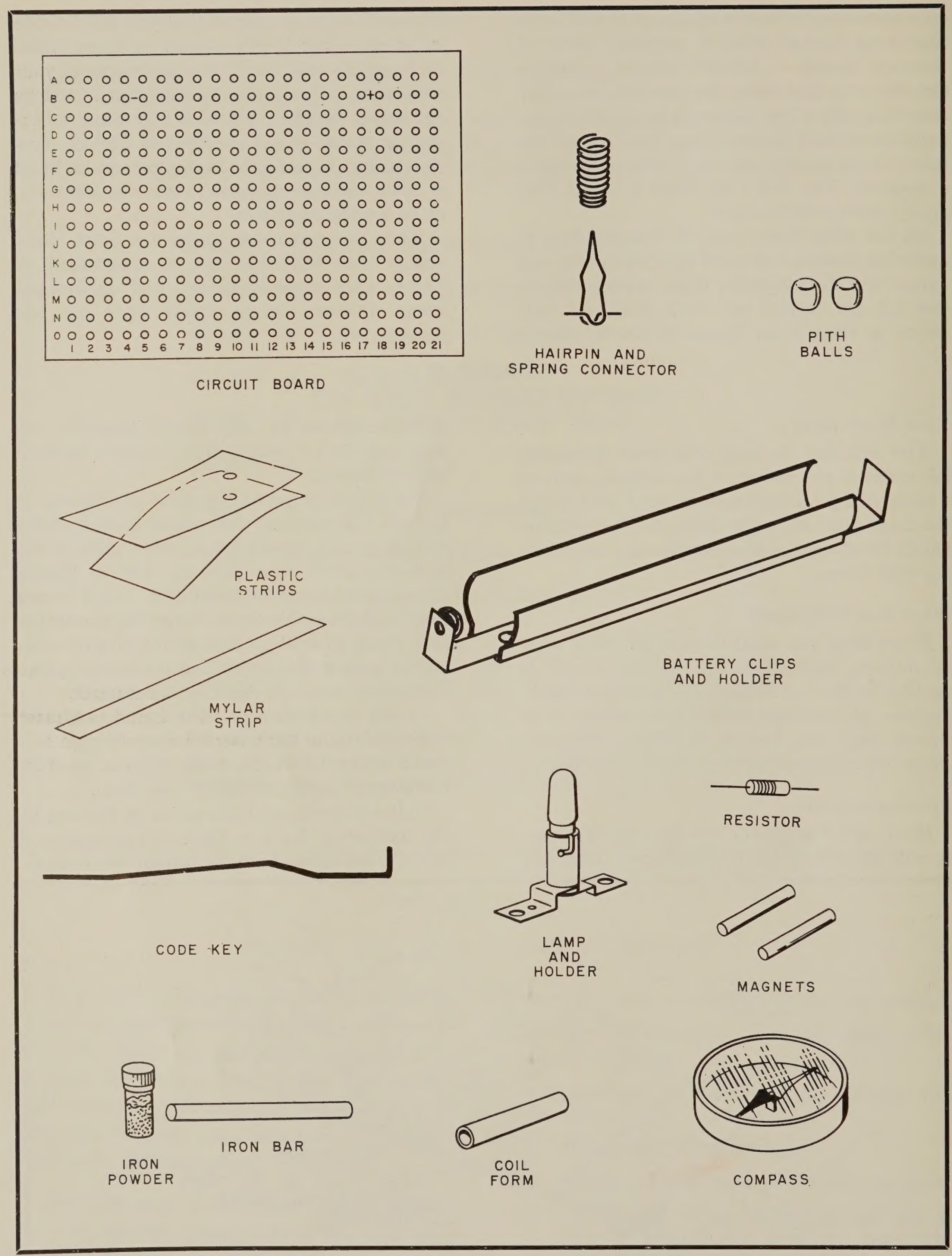

TOP TRAY
PLASTIC SHEET
CAUTION!
KEEP ENDS OF TOP TRAY AND PLASTIC SHEET TOGETHER.
BOTTOM TRAY

FIG. NO. 1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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
CIRCUIT BOARD
HAIRPIN AND SPRING CONNECTOR
PITH BALLS
PLASTIC STRIPS
BATTERY CLIPS AND HOLDER
MYLAR STRIP
RESISTOR
CODE KEY
LAMP AND HOLDER
MAGNETS
IRON POWDER
IRON BAR
COIL FORM
COMPASS

FIG. NO. 2

As you take each part from the blister trays, identify it by comparing it with the illustrations in *Fig. No. 2* on the facing page. You should find all parts except the two D-size flashlight batteries, which you should have bought. Here is some information on some of the most important items in your kit:

Circuit Board. For setting up experiments in electricity. The holes make it easy to set up and take down experiments.

Hairpin-and-Spring Connectors. To connect wires without twisting or winding them together or using solder.

Plastic Strips and Pith Balls. For experiments in static electricity.

Mylar Strip. For the "leaves" of the electroscope you will build.

Battery Clips and Holder. For mounting and connecting batteries.

Code Key and Knob. For your telegraph code practice set.

Lamp and Socket. For use in the code flasher and other experiments.

Resistor. A device for controlling the flow of electricity.

Magnets. These are small but powerful. Keep them away from watches (a magnetized watch will not keep good time) and from your compass.

Iron Bar and Iron Powder. For experiments in magnetism.

Coil Form. You will wind magnet wire on this to make an electromagnet.

Compass. To be used for purposes that will surprise you.

PART 3
PREPARING YOUR LABORATORY

One of the key components of your laboratory is the circuit board on which you will carry out many experiments. Engineers call a board like this, designed for experimenting, a "breadboard." The name goes back to the early days of radio, when experimenters mounted radio parts on ordinary kitchen breadboards.

You won't need your breadboard for the first seven experiments. However, it's a good idea to become familiar with it and get it ready now. Here are the key steps:

1. The assembly board is already mounted to a plastic frame.

2. Notice that a row of letters from "A" to "O" is printed down the left edge of the board, and a row of numbers from "1" through "21" is printed from left to right along the bottom of the board. These are to help you locate the right holes for mounting parts and making connections. To find hole [12-H], for instance, run your eye along the row of numbers until you find row 12, then down the left edge of the board until you come to row H. Hole [12-H] is where row 12 and H cross. To take another example, can you find hole [7-K]?

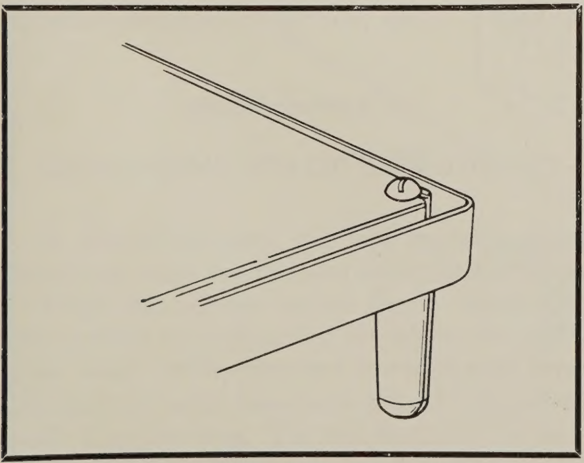


FIG. NO. 3

3. In making connections, you will use hairpin-and-spring connectors. Here's how to put them in the board. Push the loop of the hairpin up through the bottom of the board. *(See Fig. No. 4.)* Hold it in place with a flat surface, such as a book. Now, using the connector tool, push the spring firmly down over the hairpin until it clicks into place. You may have to wiggle it a little to make it stay upright. After you've experimented with the first, the rest will not be at all difficult.

To make a connection, press down the spring, as in the illustration, until you can see the loop of the hairpin. Then insert the wire through the loop and release the spring. The spring will hold the wire firmly in place.

If you should have to remove a connector, cup your hand loosely under the hairpin on the underside of the board to catch the hairpin. Then simply press down hard on the spring and hairpin. The hairpin will pop out, and the spring can be lifted out of the hole.

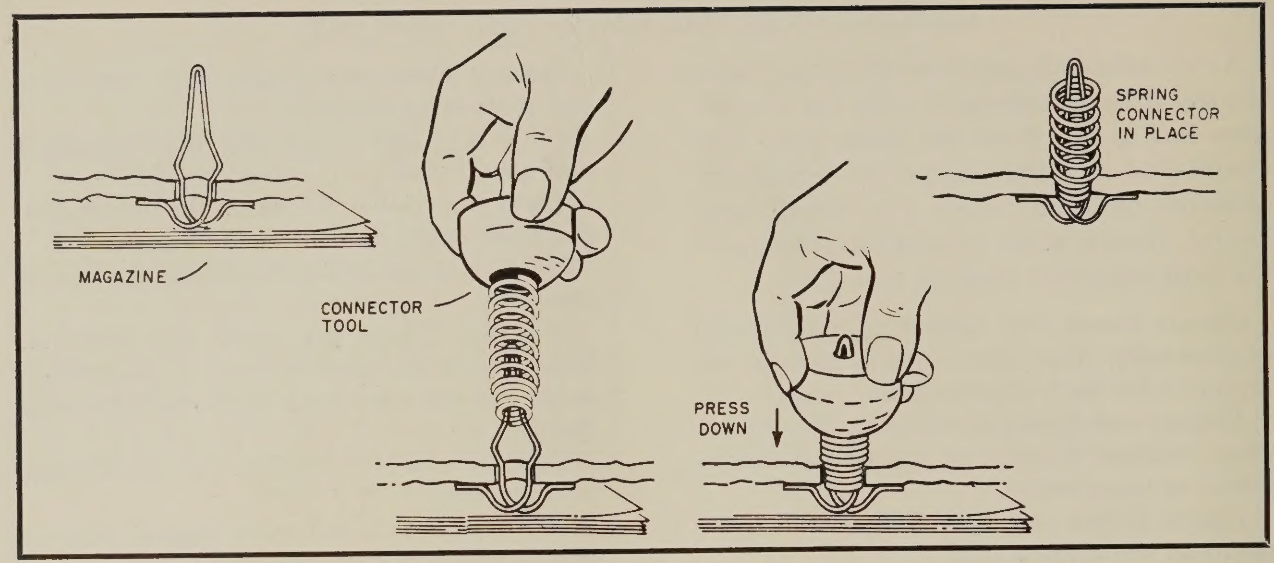


FIG. NO. 4

4. Attach battery contact spring to one battery holder clip. *(See Fig. No. 4A)*. The clip with the spring is the negative battery clip. Mount it next to the minus (—) sign on the assembly board. Mount the clips and the battery holder at the same time as shown in *Fig. No. 5.*

Bring a green wire from the positive end of the battery holder up through hole (14-C]. Bring another green wire up through hole [8-C].

Do not put your batteries in yet.

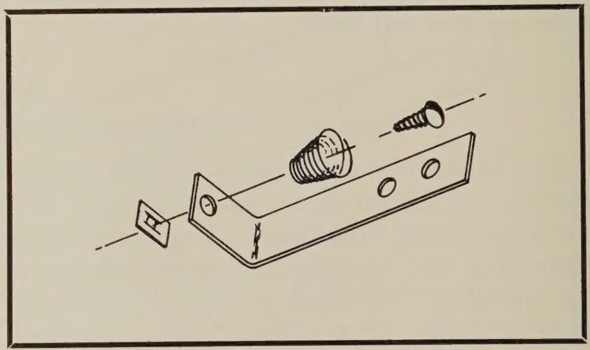


FIG. NO. 4A

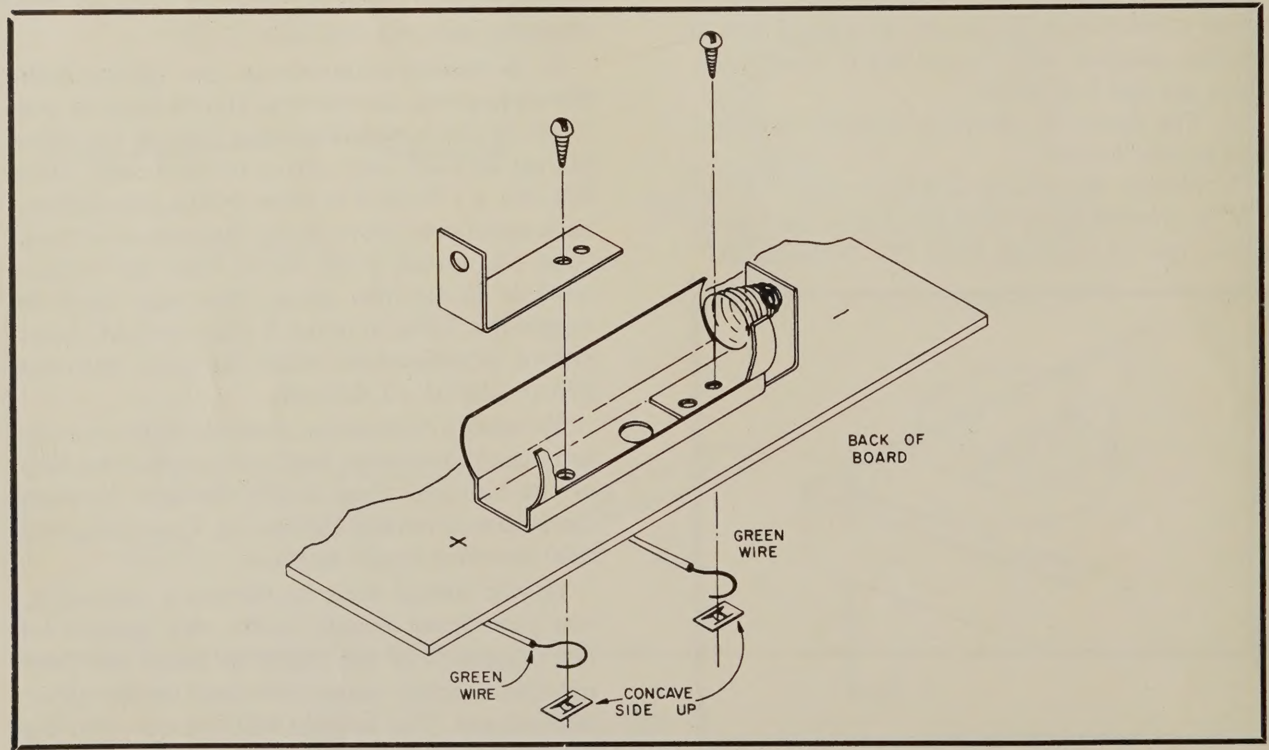


FIG. NO. 5

PART 4

STATIC ELECTRICITY

Do you know what an electric current is? Of course! It's what comes out of a wall outlet to light a lamp bulb or operate a radio. But what is it really? An electric current is a stream of tiny particles called electrons flowing through a wire from one place to another. It's this flow of electrons that does useful work.

Look at the flashlight bulb in your kit. The bulb is lighted by the flow of electrons through the very fine wire inside the bulb. And the more electrons flow through the fine wire, the brighter the bulb burns. The story is the same with an electric motor. Flow of electrons through wiring in the motor causes it to turn.

In most of the experiments you will do with this kit, you will be working with battery electricity — with the flow of electrons from a battery. These will be small currents from flashlight batteries, so there is no danger of electric shock. In order to understand electricity, however, it helps to start with what is called "static electricity." This is electricity that mostly stays in one place ,as the word "static," which means "not moving," tells you.

Incidentally, these first static electricity experiments work best when the weather is cool and dry. On damp days, the electrons are likely to flow away from your apparatus instead of staying where you can study them. Therefore, if you have difficulty with a static electricity experiment, try it again on a drier day. On the other hand, on a *very* dry day, you may generate static electricity yourself by rubbing your shoes on a wool or nylon rug. This can interfere with your experiments, too. On such days, spread newspaper under your feet.

Experiment 1.

GENERATING STATIC ELECTRICITY

In this experiment, you will generate static electricity with the red and clear plastic strips.

Place the plastic insert sheet, which you saved when you unpacked the blister trays, on your work table. Unwind some thread from the galvanometer frame and cut off two pieces, each 5 inches long. Tie one through the hole in each strip of plastic. Cut off any dangling thread at the short end of each thread to prevent it from getting in the way.

Lay the red plastic on the plastic insert sheet and rub it with the clear plastic, as in *Fig. No. 6*. Rub fairly hard.

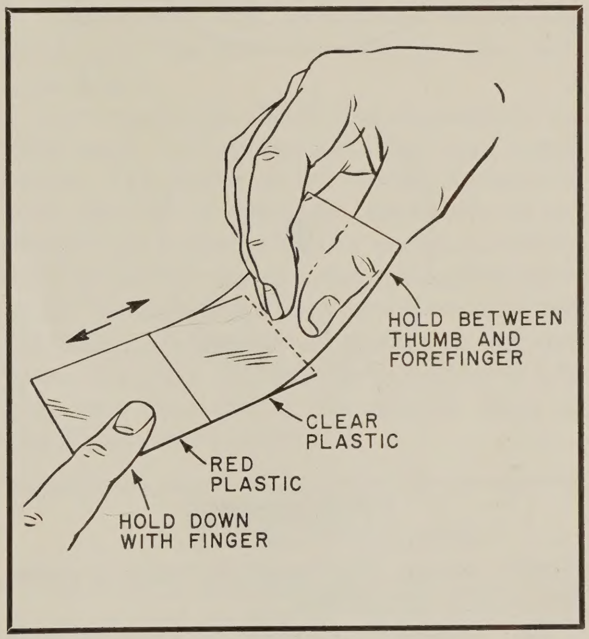


FIG. NO. 6

Now take a thread in each hand, and lift the strips into the air. They should stick together. Pull them apart, then bring your hands close together so that the strips are side by side. The strips should attract each other. Bring them a little closer; the strips should jump together.

Here is why the two strips attract each other. As you know, all matter is made up of atoms. And atoms, though tiny, are made up of tinier particles still. Two kinds of particles, *protons* and *neutrons*, are bunched at the center or *nucleus*. A third kind, *electrons*, whirl around the nucleus, much as man-made satellites whirl about the earth. Each of the hydrogen atoms shown in *Fig. No. 7* has one electron and one proton.

Your strips of plastic are made up of three kinds of atoms: hydrogen, carbon, and oxygen. Of course an atom is much too small to be seen in even the most powerful microscope.

Each electron has what we call a *negative*

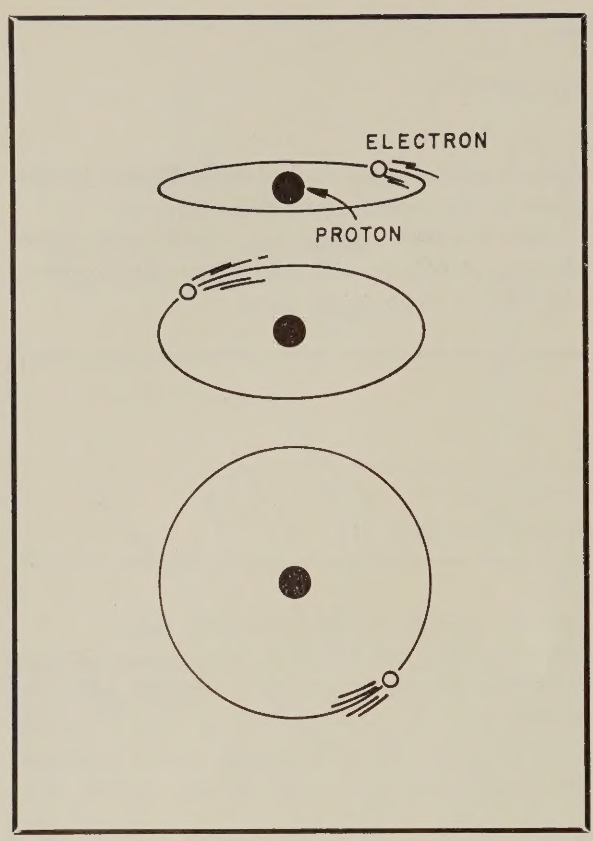


FIG. NO. 7

electric charge. The negative charge is represented by a minus sign.

The nucleus of a hydrogen atom consists of a single proton. A proton has an electric charge of an opposite kind, which we call a *positive electric charge,* and which is represented by a plus sign. The positive electric charge of a proton is just as great as the negative electric charge of an electron. Since the two charges in a hydrogen atom are equal and opposite, they cancel each other. So a hydrogen atom acts as though it doesn't have any electric charge. We say it is electrically *neutral.*

In each other kind of atom except hydrogen, the nucleus contains both protons and neutrons. Neutrons have no electric charge, but every nucleus has a positive charge from the protons in it. The number of protons is the same as the number of electrons. Thus the electric charges in an atom cancel out and atoms are electrically neutral. For example, there are 6 electrons in a carbon atom. There are also 6 protons plus 6 neutrons in the nucleus. The electric charges of the electrons and protons cancel out to make the carbon atom neutral.

When you rubbed the two strips of plastic together, some of the electrons from the red strip moved into the clear strip. This gave the clear plastic extra electrons and an extra negative charge, as in *Fig. No. 8.* The red plastic was left with a positive charge because it had fewer electrons to balance the positive charges inside its atoms.

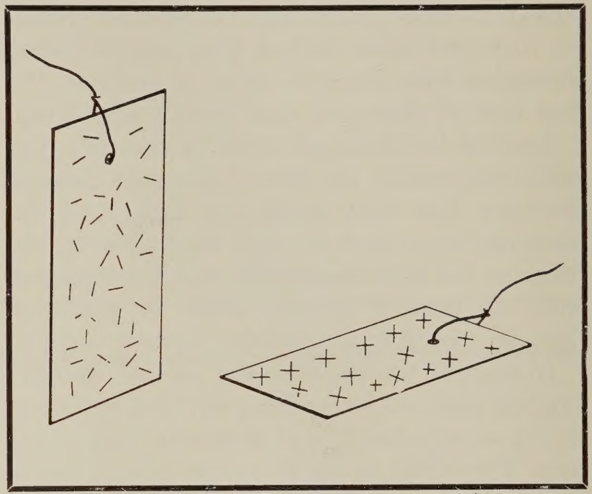


FIG. NO. 8

Why do the two strips — one with a negative charge and the other with a positive charge — now attract each other? Because *positive and negative electricity attract each other.* This is a basic law of nature.

Static electricity is generated only when you rub *different* materials together. When you rub together the red and clear plastics, you generate electricity because the clear plastic has stronger power to hold electrons than the red plastic.

The reason you *rub* the two strips together instead of merely touching them to each other is to bring more of their surfaces into contact. If you examined the plastic strips with a very powerful microscope, you would see that their surfaces are rough. If you simply placed the two strips together, only the points that stick out would touch, and thus only a small amount of static electricity would be generated.

Experiment 2.
CONDUCTORS

Charge the red and clear plastic strips by rubbing them together as you did in Experiment 1. Test them to make sure they attract each other.

Now rub your fingers over both sides of both plastic strips, so that you touch every part of the strip. Lift them by the threads and bring them close together. Do they still attract each other?

The two strips no longer attract each other because you have made them electrically neutral. When you rubbed your fingers over the red plastic, the positive charge on it attracted electrons from your body. These flowed out onto the strip through your fingers to neutralize its positive charge.

Did your body acquire a positive electric charge when electrons left it? Yes, it did, but your body is so much larger than the strip of plastic that you would not notice the loss of electrons. It's as though you took a drop of water from a lake.

In the same way, when you rubbed your fingers over the clear plastic, extra electrons went from it to your body. This left the plastic nearly neutral and gave your body extra electrons. But again, the charge on your body was too small to notice.

Now, find the iron rod in your kit. Then, charge the two strips again. Leave the red plastic on the plastic insert sheet. Hold the clear plastic in one hand and the iron rod in the other. Touch the iron rod against both sides of the clear plastic and along the edges. Touch every part of the strip, except the end you are holding.

Now rest the clear plastic on the insert sheet. Take the red plastic and touch it with the iron rod in the same way. Test the two strips of plastic. Do they still attract each other?

When you touched the red plastic with the iron rod, electrons flowed from your body, through the rod, and into the plastic, and neutralized the strip's charge. When you touched the clear plastic with the rod, the extra electrons on the clear strip flowed through the rod and into your body, leaving the plastic electrically neutral.

Since electrons flowed through the iron rod, we say that iron is a *conductor* of electricity. And here is something important and useful to know: All metals are conductors of electricity, and most metals are very good conductors. That is, they offer little *resistance* to the flow of electrons. Metals are good conductors because they contain electrons that are not tightly bound to atoms, but are relatively free to move around. This is why electrons could flow through the iron rod.

Experiment 3.
INSULATORS

Charge the two strips again, and see if you can *discharge* them (make them electrically neutral) by touching them with the plastic handle of your screwdriver. Just touch them gently. Don't rub so hard that you generate more static electricity.

Do the strips still attract each other?

They should — unless you were careless and discharged the strips by rubbing them with your fingers.

This experiment shows that electrons do not flow easily through the handle of your screwdriver. The plastic of the handle strongly *resists* the flow of electrons. Therefore, we say that it is an *insulator*. Unlike metals, insulators have no free electrons. Electrons cannot move easily through them. And here is another useful thing to remember: Most plastics are very good insulators. (Do you understand now why you have been resting the charged strips on the plastic insert sheet?)

Experiment 4.
ELECTRICAL REPULSION

Cut a piece of thread about 16 inches long. Tie a pith ball on each end. Hang the balls as in *Fig. No. 9.*

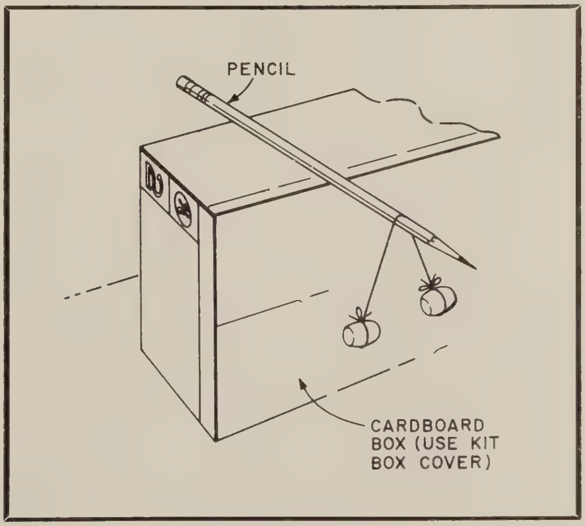


FIG NO. 9

Rub the charged side of the clear plastic against the pith balls. Don't touch either the pith balls or the thread with your fingers.

Take the plastic away. The pith balls should repel each other, as shown in *Fig. No. 10.*

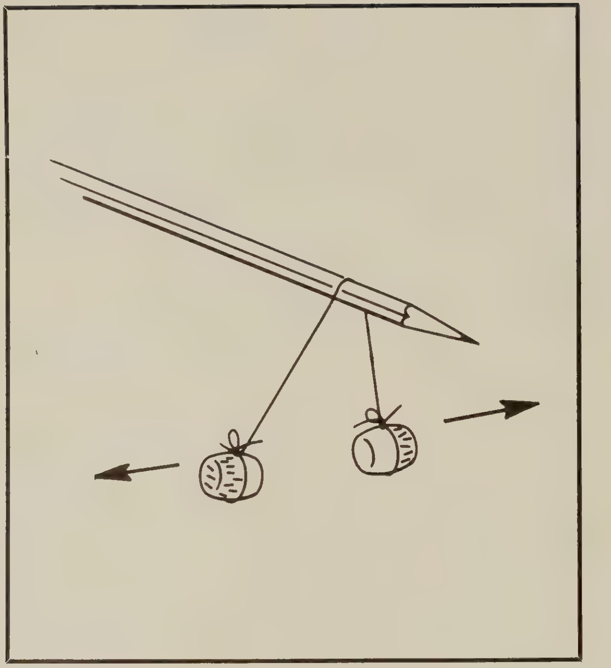


FIG. NO. 10

This is what happened: When you touched the pith ball with the negatively charged clear plastic, some of the extra electrons on the plastic flowed on to the ball as in *Fig. No. 10.* Now both pith balls had a negative charge, and it is a law of nature that like charges repel each other.

Now bring the charged clear plastic near the pith balls. What happens? They are repelled away from the plastic strip. Do you know why?

Notice that in *Fig. No. 10* the negative charges are shown on the *far* ends of the pith ball. Can you explain why?

The reason is that the extra electrons repel each other. This repulsion drives them to the surface, where they can be as far apart as possible. Interestingly, this also happens in wires carrying an electric current. We often speak of electricity flowing "through" a wire. Electrons really flow along the surface, to be as far apart as possible, just as in the pith balls.

Now neutralize the pith balls with your fingers. Charge the plastic strips again, but this time use the red plastic, which will have a positive charge. Rub the red plastic against the balls, so that electrons will flow from the balls to the plastic. Now both the balls and the plastic are positively charged. Test them to see if they repel each other.

They do indeed. *Like repels like for positive charges, just as for negative charges.*

Experiment 5.
ATTRACTING NEUTRAL OBJECTS

Neutralize the pith balls by touching them with your fingers. Charge the strip of red plastic as you did in the last experiment, and bring the strip close to the pith balls. The balls should swing out to meet the plastic. But try not to let the balls touch the plastic.

Fig. No. 11 explains why the ball is attracted. When you charged the red strip, it lost electrons and so was left with a positive charge. This pulled electrons over to the side of the balls near the plastic, when the plastic was brought close. At the same time, positive charges were repelled, putting a positive charge on the far side of the ball; this is called induction charging. But since the negative charges are closer to the plastic than the positive charges, they are attracted more strongly than the positive charges are repelled, and the ball is attracted to the plastic strip. This explains how an object with an electric charge can attract neutral objects.

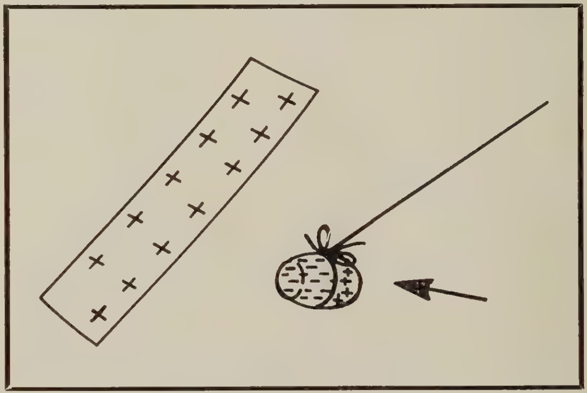


FIG. NO. 11

Repeat the experiment using the clear plastic. (If you accidentally touched the pith ball with the red plastic, neutralize the ball with your fingers before testing it with the clear plastic.)

Take the sheet of tissue paper in your kit and tear off a half dozen very small pieces. Put them on your laboratory breadboard and hold a charged strip of plastic a little distance above them. Notice how the scraps of paper are attracted to the strip. Again, they have been charged by induction.

Try holding a charged strip a little above your head and see if you can make your hair stand on end.

Experiment 6.
THE ELECTROSCOPE

The electroscope is an important instrument for detecting and measuring electric charges.

Before building it, study *Fig. No. 12.* Obtain a glass jar and collect the parts you will need from your kit.

To make your electroscope, first insert the straight end of the electroscope stem through the hole in the fiber disc. Put the sleeve over the stem, with the wider part (the flange) away from the disc, as shown in *Fig. No. 12.*

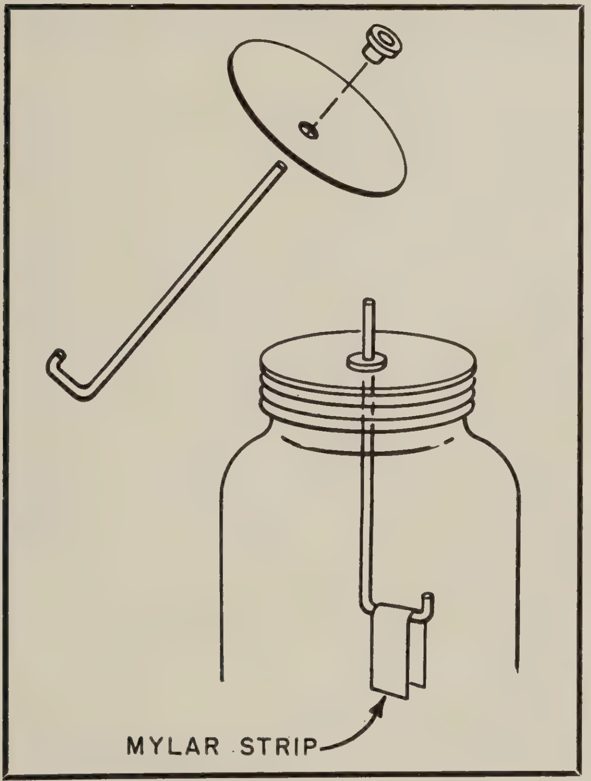


FIG. NO. 12

Now push the sleeve down the stem until it is about an inch from the end. Snap the sleeve into the hole in the fiber disc, with the flange right against the disc. Turn the stem so that the hooked part is under the center of the disc. Set the disc over the mouth of the glass jar.

Examine the Mylar strip carefully. This is a strip of plastic with a very thin layer of metal on one side. Both sides look shiny, but the side with the metal is shinier. Fold the strip in the middle with the metal side inside. Crease the fold sharply between your fingers and roll it back and forth a little as in *Fig. No. 13.*

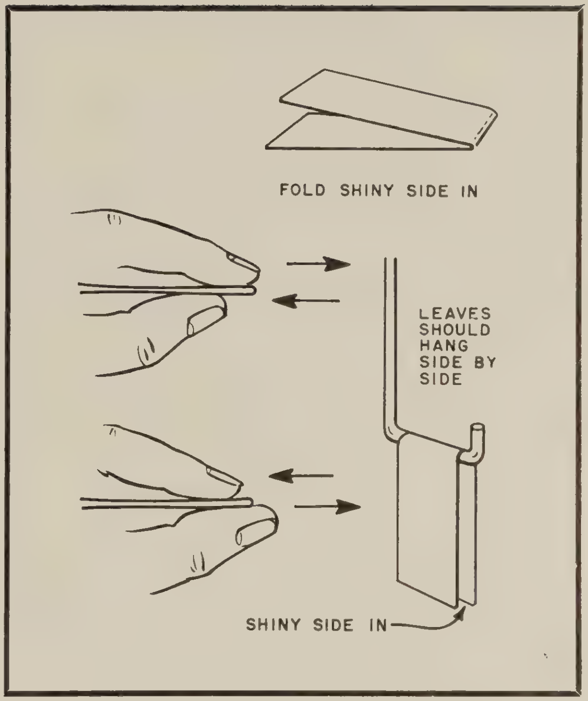


FIG. NO. 13

Now hang the strip over the hook. The two ends should hang as in *Fig. No. 13.* But if they are further apart, take the strip off the hook and sharpen the crease between your fingers.

Next, rest the disc on the mouth of the jar, with the Mylar strip hanging inside, near the center of the jar.

Your electroscope is finished. Let's see how it's used.

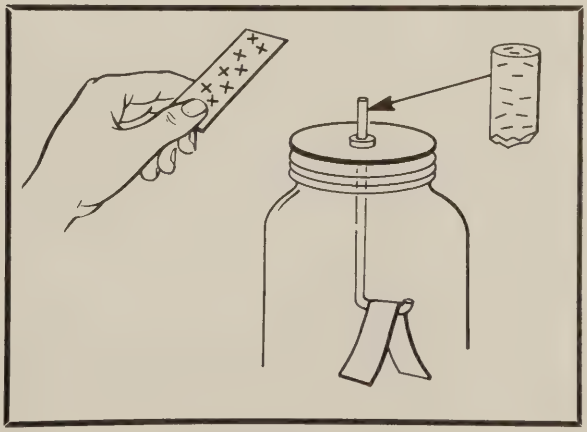


FIG. NO. 14

Charge the red plastic strip and hold it close to the upper end of the electroscope stem. Watch what happens. The two leaves should move apart as in *Fig. No. 14.* (They are called "leaves" because in many electroscopes, they are actually made of gold leaf.)

Now move the red plastic away. The leaves should fall together again.

Here is why the leaves moved apart: The red plastic had a positive charge. It therefore attracted electrons from the leaves to the top of the stem. This left a positive charge on both leaves, causing them to repel each other. Then, when you moved the charged plastic away, electrons were no longer attracted to the top of the stem. Therefore the leaves became neutral again and fell back together by the force of gravity.

Notice that you did not change the total charge on the electroscope. All you did was attract some of the electrons to the top.

Charge the red plastic strip again, and this time rub it gently over the top of the stem so that the stem touches different parts of the plastic. (Be sure you use the side of the plastic on which the charge is concentrated.) Now the leaves should remain apart after you take the plastic strip away.

This time, of course, you did change the total charge on the electroscope. Which way did electrons flow, into the plastic or into the electroscope? What kind of charge is on the electroscope?

Discharge the electroscope by touching the stem with your finger. The leaves should fall together immediately. Which way did electrons flow, into your body or into the electroscope? (If the leaves do not fall together, that means you have a little static electricity on your body. To avoid generating static electricity as you work, spread newspaper beneath your feet as suggested on Page 7.)

Experiment 7.

CHARGING BY INDUCTION

Discharge the electroscope and recharge the red plastic strip. Hold the strip near the stem, as in Experiment 6. The leaves move apart, as shown in *Fig. No. 14.* Keeping the red plastic near, but not touching the electroscope stem, touch the stem with a finger of your other hand. The leaves should collapse. Now remove first your finger, then the plastic strip. The leaves should spread apart again. Now bring the red strip near the stem. The leaves collapse, showing that they have a negative charge (the red strip is positive). So, a negative charge was obtained from a positively charged strip!

When you first brought the red strip near the stem, charges distributed themselves as in *Fig. No. 14.* When you touched the stem, electrons flowed from your finger into the electroscope to balance the positive charge on the leaves. When you removed your finger, the electroscope was left with excess electrons, or a negative charge. This is a fast way to charge your electroscope, but remember that the charge on the leaves is opposite to that of the strip used for charging.

PART 5

INTRODUCTION TO ELECTRIC CIRCUITS

Now you are going to leave static electricity and start experimenting with *electric circuits.* The word *circuit* is like *circle,* and it suggests that in an electric circuit the electrons flow around in a sort of circle.

Why is this important?

The trouble with static electricity is that we can't make it do much useful work. For example, suppose we had a pair of large metal spheres, one with a large negative charge on it. If we connected them as in *Fig. No. 15,* electrons flowing from the sphere with the negative charge would make the light bulb light, but only for a very short time. Soon the two spheres would have the same charge, and no more electrons would flow through the lamp.

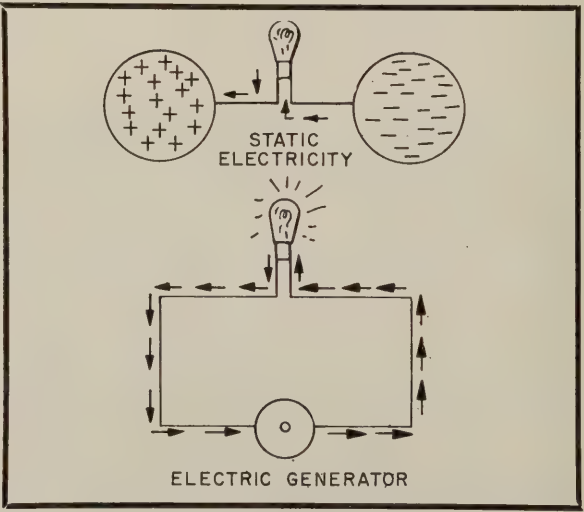


FIG. NO. 15

The solution to this problem is to use an electric generator to take the electrons that come out of the light bulb at the left and move them back to where they started from so that they will go through the light bulb again, as shown in *Fig. No. 15*. This is an electric circuit.

Notice that an electric generator doesn't produce electrons. It just makes electrons move. In other words, it acts as a sort of pump.

When we speak of an "electric generator," we usually mean a machine built something like an electric motor. But in the experiments that follow, you'll use flashlight batteries to make electrons move through circuits. Batteries are safer and easier to work with.

In your experiments you'll be working with *direct current* or *DC*, in which the electrons always flow in the same direction. Chances are, your house current is *alternating current* or *AC*. In most parts of the United States, house current is AC. In alternating current, electrons flow first in one direction, then the other. Most of the AC current in the U.S. is "60-cycle" AC. This means that the electrons make 60 back-and-forth surges a second.

Now let's start building your first circuit.

Experiment 8. MAKING A CODE FLASHER

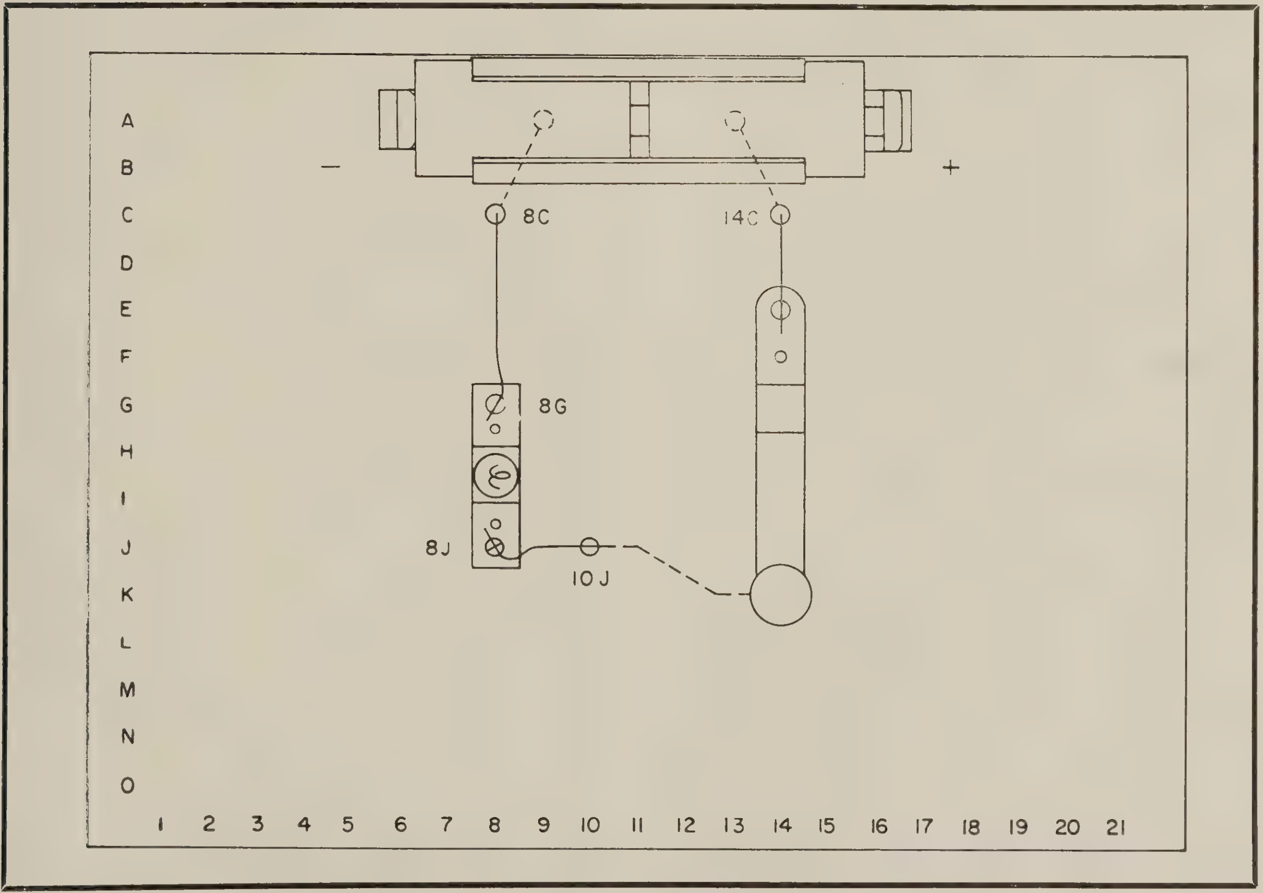


FIG. NO. 16

The code flasher and the parts you will need for it are shown in *Fig. No. 16*. The wires that go under the board are shown by dotted lines.

If you did not do it before, prepare your circuit board, as described in "Preparing Your Laboratory" on Page 5.

Put the lamp bulb in the socket. Push the hairpin part of a connector up through holes [8-G] and [8-J]. Place the socket over the hairpins, and fasten it by fitting springs onto the hairpins, as in *Fig. No. 17*. Connect the green wire that comes up through hole [8-C] to the connector at [8-G]. To connect the wire, push down the spring and slip the wire through the hairpin. The wire will be held firmly in place when you release the spring.

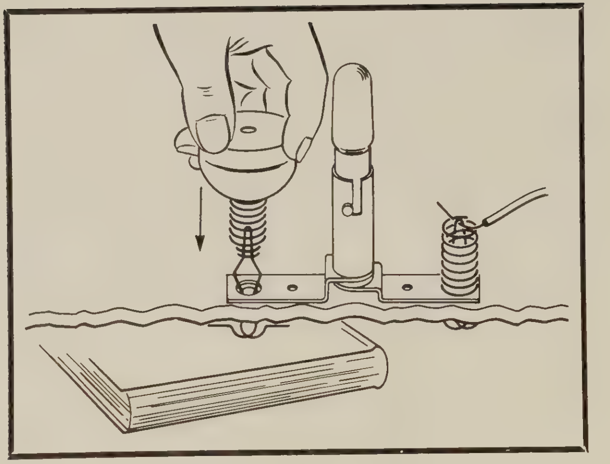


FIG. NO. 17

Now assemble the code key. Find the 1½" x 2½" code key base, then place a screw in the hole nearest the center hole *(See Fig. No. 18)*. Now take the code key shaft and place a paper clip through the hole in the center of the shaft and through the center hole of the code key base. Bend the clip ends over, leaving the shaft loose. Do not tighten shaft. It will make contact with the screw head later.

Now insert a spring on the remaining paper clip and place it through the end hole in the code key shaft, then through the code key base, and mount to the assembly board. Bend leads over.

For a knob, place the round tool connector on the upright corner of the shaft. Press the knob down. The code key shaft should "make" and "break" contact with the screw head as you press down the key knob.

Attach a green wire around the screw underneath the assembly board using a speednut to hold it on tightly. Attach the wire from [14C] to the wire spring that is on the paper clip.

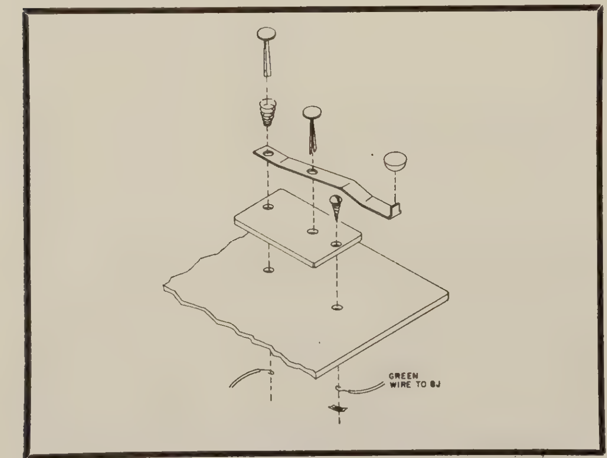


FIG. NO. 18

Now put the batteries in. Note carefully which end of the battery is negative and which positive. *(See Fig. No. 16.)*

Check your flasher against *Fig. No. 16*. Press down on the key. The bulb lights? Your code flasher is finished.

Using the Code Flasher

The code flasher will not only enable you to spell out letters in dots and dashes and practice Morse code if you like, but it illustrates an electric circuit. When you are not pressing down on the key, there is a gap in the key. Electrons from the batteries cannot cross it. So no current flows and the bulb is not lighted. As electricians say, the circuit is *open*. When you press down the key, the circuit is *closed*, electrons flow and the bulb lights.

Instead of drawing a picture of a circuit, as in *Fig. No. 16*, workers with electricity usually draw a simpler type of diagram called a *schematic diagram*. In this, the different parts are represented by symbols. *Fig. No. 19* is a schematic diagram of your code flasher.

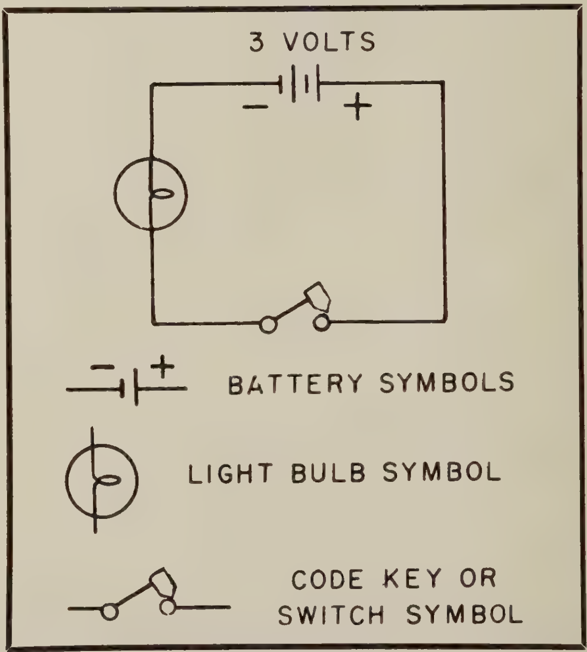


FIG. NO. 19

If you would like to use the flasher to practice code, you will find the Morse code on Page 38. To make a dot, press the key down and release it instantly. To make a dash, hold the key down longer. However, you will be building another type of code practice set later. In any case, leave your code flasher on the board, because you will use almost exactly the same circuit in the next experiment.

Experiment 9.

BATTERIES IN SERIES

Press the key of your code flasher for a moment, and notice how bright the bulb is.

What will happen if you use only one battery instead of two? To try this, first remove the negative battery wire from connector [8-G]. Attach one end of a blue wire to connector [8-G]. Holding the key down with one hand, touch the unconnected end of the blue wire *between* the two batteries.

Now you are operating the bulb on one battery only. When new, a single flashlight battery gives about 1.5 volts. When you use the two batteries together, you get about 3.0 volts. This forces more current through the light bulb, causing it to burn more brightly.

How much current flows through the light bulb when it is connected across a 1.5-volt battery? There's a handy, simple way of figuring it out, called Ohm's Law. You can read about it below.

Now remove the blue wire from between the batteries. Put your circuit back the way you had it before as in *Fig. No. 16.* Take the battery at the left out, turn it around, and put it back in. Press the key. The bulb should not light at all because the two batteries are trying to push electrons in opposite directions.

When the batteries are both pushing electrons in the same direction, one behind the other, this is called connection in *series.* When they are pushing against each other, this is called *series opposition.*

Put the batteries back the way they were — connected in series — before proceeding to the next experiment.

OHM'S LAW

Let's pause a moment in our experiments to meet three scientists.

Alessandro Volta was an Italian who lived from 1745 to 1827. The *volt* is named after him.

Georg Ohm was a German. He lived from 1787 to 1854. The *ohm* is named after him.

Andre Ampere was French. He lived from 1775 to 1836. The *ampere* is named for him.

What are volts, ohms and amperes anyway?

Like everything else in the world, electricity has a way of being measured. We know that electricity can do work — and the amount of work depends on the quantity of electrons flowing through a device. In a light bulb, for example, the electricity does work in creating light; in an electric stove, in creating heat; and in a phonograph or radio, sound. Electrons are the workers. The more electrons, the more work that can be done. The number of electrons flowing in a line is measured in *amperes.*

Electrons, however, are tiny. It takes a great many to make a sizeable current. You know that a flashlight battery does not give a very large current. In fact, it is about one quarter ampere. But a current of one quarter ampere is a flow of 1,570,000,000.000,000,000 electrons per second.

Of course, electrons must be pushed in order to flow. The push is furnished, in the circuits you are building, by the repulsion of the negative terminal of the battery and the attraction of the positive terminal for the negative electrons. The push is measured in *volts.*

In your experiments, you have found that materials differ in their ability to conduct a current. In other words some materials, most metals for example, offer little resistance to a current. Others are insulators and offer high resistance to the flow of electrons. Resistance is measured in *ohms.*

About a century and a quarter ago, Georg Ohm discovered that the flow of current (amperes), the push on a current (volts) and the resistance (ohms) are related. The greater the push, the greater the flow. The greater the resistance, the less the flow. He stated it this way:

$$\text{AMPERES} = \text{VOLTAGE} \div \text{OHMS}$$

Scientists usually use the letter I as the symbol for amperes; E for volts; and R for resistance. And they write Ohm's law thus:

$$I = \frac{E}{R}$$

Ohm's Law can be used to make many calculations about electric circuits. Let us use it to see why two batteries in series made the bulb burn brighter than one.

The bulb supplied in your kit has a resistance of 33 ohms. Each battery gives electrons a "push" of 1.5 volts. For one battery therefore,

Current through bulb =
1.5 ÷ 33 = .045 amperes.

As we saw in the experiment, when batteries are connected in series, the "pushes" add up. So two flashlight cells in series give a total push or voltage of 3 volts. Therefore,

3 ÷ 33 = .091 amperes.
Current through bulb =

No wonder the bulb burned more brightly with two cells in series. Twice as much current was flowing through it.

The repulsion of electrons for electrons has a lot to do with making an electric current flow. Electrons, flowing into a wire, repel other electrons and make them flow. The speed at which the electrons themselves move is usually very slow, perhaps a foot or so an hour. But the repulsion effect passes from electron to electron along the wire at great speed — perhaps 186,000 miles a second in a copper wire. That's why we can send signals with electricity very swiftly, even though the electrons themselves move at a snail's pace.

Experiment 10. RESISTANCES IN SERIES

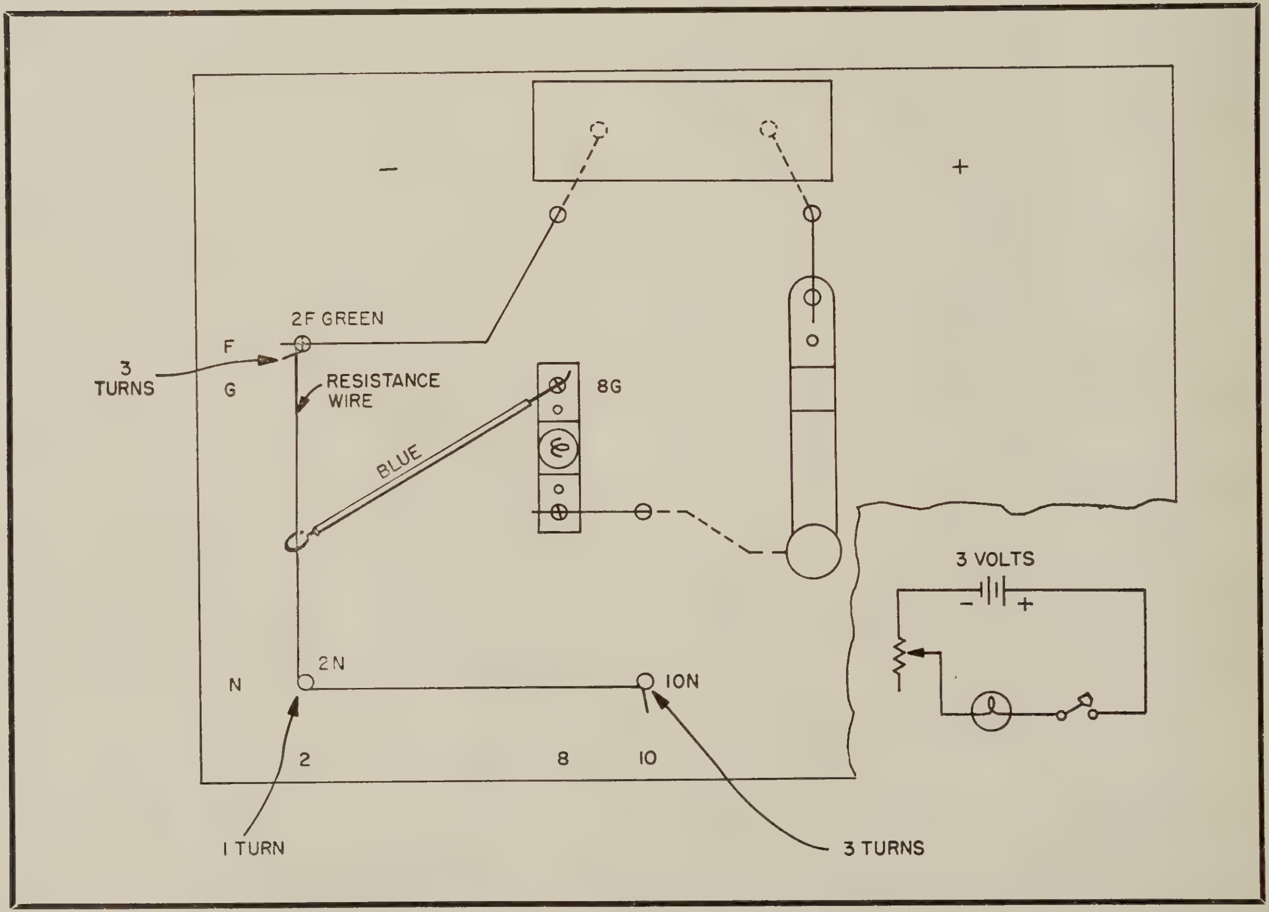


FIG. NO. 20

Set up your breadboard as shown in *Fig. No. 20*. Put connectors in holes [2-F], [2-N] and [10-N]. Unwind the thin bare resistance wire from the galvanometer frame, taking care not to kink it. Wrap one end three times around the spring at [2-F]. Pull the other end just hard enough to keep the wire stretched out tight — but not any harder. Wrap the wire once around the spring of connector [2-N]. Wrap the end three times around the spring of connector [10-N].

Remove the green wire from [8-G] and connect it to [2-F]. Connect a blue wire to connector [8-G]. Bend the other end into a small hook. We will call this end your "test probe." Now you are ready to experiment with resistances in *series.*

Press the code key and touch the probe to connector [10-N], then to [2-N], then to [2-F]. Slowly slide the probe along the wire from [2-F] toward [2-N] while you watch the bulb.

The resistance wire is made of an alloy of nickel and chromium. The alloy has much higher resistance to electricity than most metals, especially high when the wire is very thin like the piece you're using. Each inch of the wire has a resistance of about 2.8 ohms. When you moved your probe toward [2-N], you were putting more and more resistance into the circuit. We say "putting resistance in series in the circuit," because the electricity must flow through it, just as electricity flows through one battery after another when the batteries are in series.

Remember this rule: when resistances are connected in series, you find the total resistance by adding together the separate resistances.

For example, what is the total resistance of the light bulb plus the resistance wire when your probe is at [10-N]? (The connecting wires have low resistance. We can ignore them.) The light bulb has about 33 ohms resistance. The wire stretches across 16 holes, or 8 inches. Eight inches of wire, at 2.8 ohms per inch, has a resistance of 22.4 ohms. Therefore, the total resistance is:

$$22.4 + 33 = 55.4 \text{ ohms.}$$

See if you can figure out the total resistance at other points.

Leave your breadboard setup. You will use the resistance wire in the next experiment. But before going on, can you tell which symbols in the schematic diagram in *Fig. No. 20* represent the actual parts on your board?

Experiment 11.
PARALLEL CIRCUITS

You have experimented with batteries and resistors connected in series. There is another simple way of connecting them: in *parallel.* This is illustrated in *Fig. No. 21.*

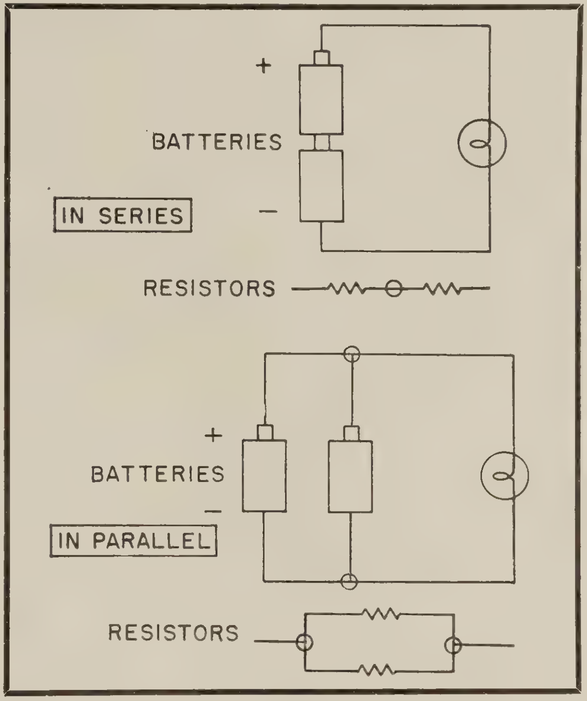


FIG. NO. 21

Let's start with resistances in parallel, since your breadboard is set up for resistance experiments. A schematic diagram of the circuit you will use is shown in *Fig. No. 22A.* You can set this circuit up without moving your resistance wire.

Join connector [2-N] to connector [8-G], using the blue wire probe for this.

Now attach one end of your other blue wire to [10-N]. At this point you have set up the circuit shown in *Fig. No. 22B.* Press the code key. Notice how bright the bulb is.

Touch the free end of the blue wire to connector [2-F] and notice the brightness of the bulb. With the blue wire connected, you have the circuit in *Fig. No. 22C.* The bulb is brighter (more current is flowing) with the wire touching [2-F] or, in electrical terms, with the two resistances in parallel.

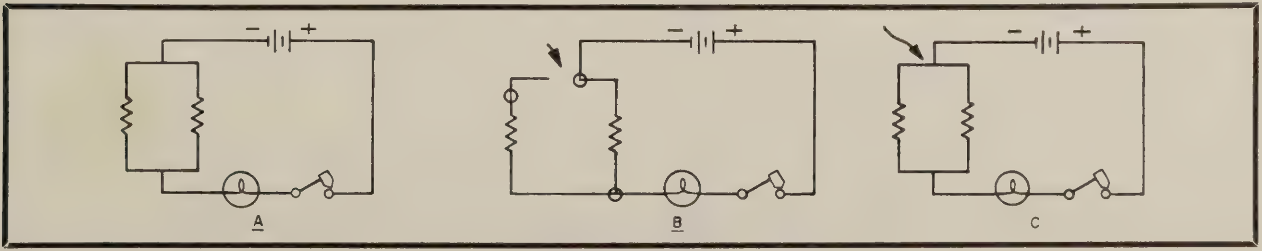


FIG. NO. 22

In fact, the total resistance of the two 4-inch lengths of resistance wire is now only 5.6 ohms — just half the resistance of a single 8-inch length.

Why does connection in parallel decrease the total resistance? Because the electrons have two "passageways" through which to travel. This means that there are more free electrons at every point along the wire to carry the current along.

Now *carefully* unwind the resistance wire from the three connectors. Coil it loosely and put it away in a blister tray for use later. Also remove and put away the connector at [2-N] and the two blue wires. Reconnect the negative battery wire to [8-G].

Study the circuit in *Fig. No. 23.* This shows batteries in parallel. What do you think the voltage between points A and B is, 0 volts, 1.5 volts, or 3.0 volts?

To test this, turn the battery at the right around so that the buttons on the two batteries touch each other. Remove the battery wire from [14-E] and connect it to [8-G], with the other battery wire. Attach one end of a blue wire to connector [14-E]. Insert the other end between the battery buttons. Press the key and note the brightness of the bulb.

Remove one of the battery leads from [8-G]. Now you are using only one of the batteries. Notice how bright the bulb is on 1.5 volts.

The bulb has the same brightness whether on one battery or on two in parallel. With two batteries in parallel you get only 1.5 volts — the same as from a single battery.

To save battery drain, don't leave the circuit as it is for long. Disconnect the circuit by first removing the battery wires from [8-G]. Remove the blue wire from the board. Turn the battery at the right back to its usual position. Connect the positive battery lead to [14-E] and the negative battery lead to [8-G]. Press the key to make sure the circuit is working.

Why do two batteries in parallel give the same voltage as one battery? Suppose you had a big battery, which you cut in half. Each half would give the same voltage as the "parent" battery. Two batteries in parallel are like the big battery cut in half.

Two batteries in parallel, however, can give twice as much current as one small battery. In the circuit we have just studied, though, they do not, because the voltage is the same and the resistance (the bulb) is the same. According to Ohm's Law (see Page 15), the current in the circuit must therefore remain the same. But the two batteries in parallel share the load. Each supplies half the necessary current.

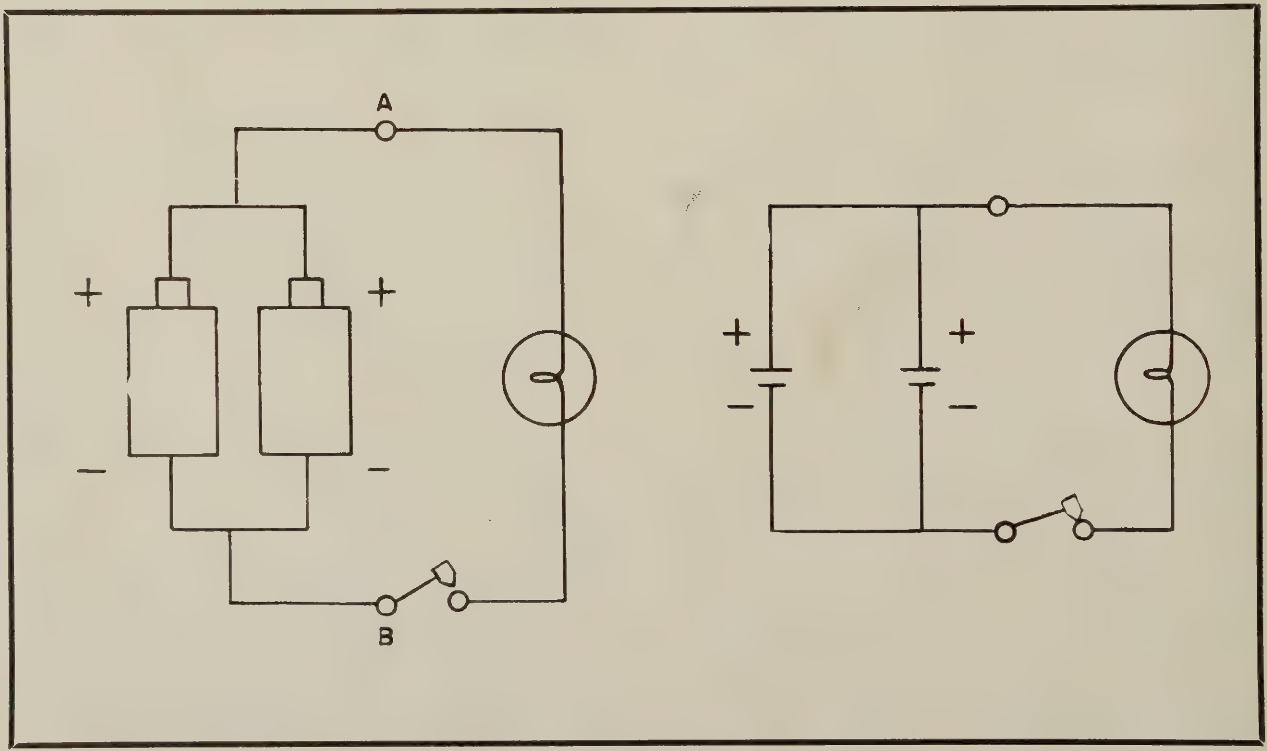


FIG. NO. 23

Experiment 12. IONIC CONDUCTION

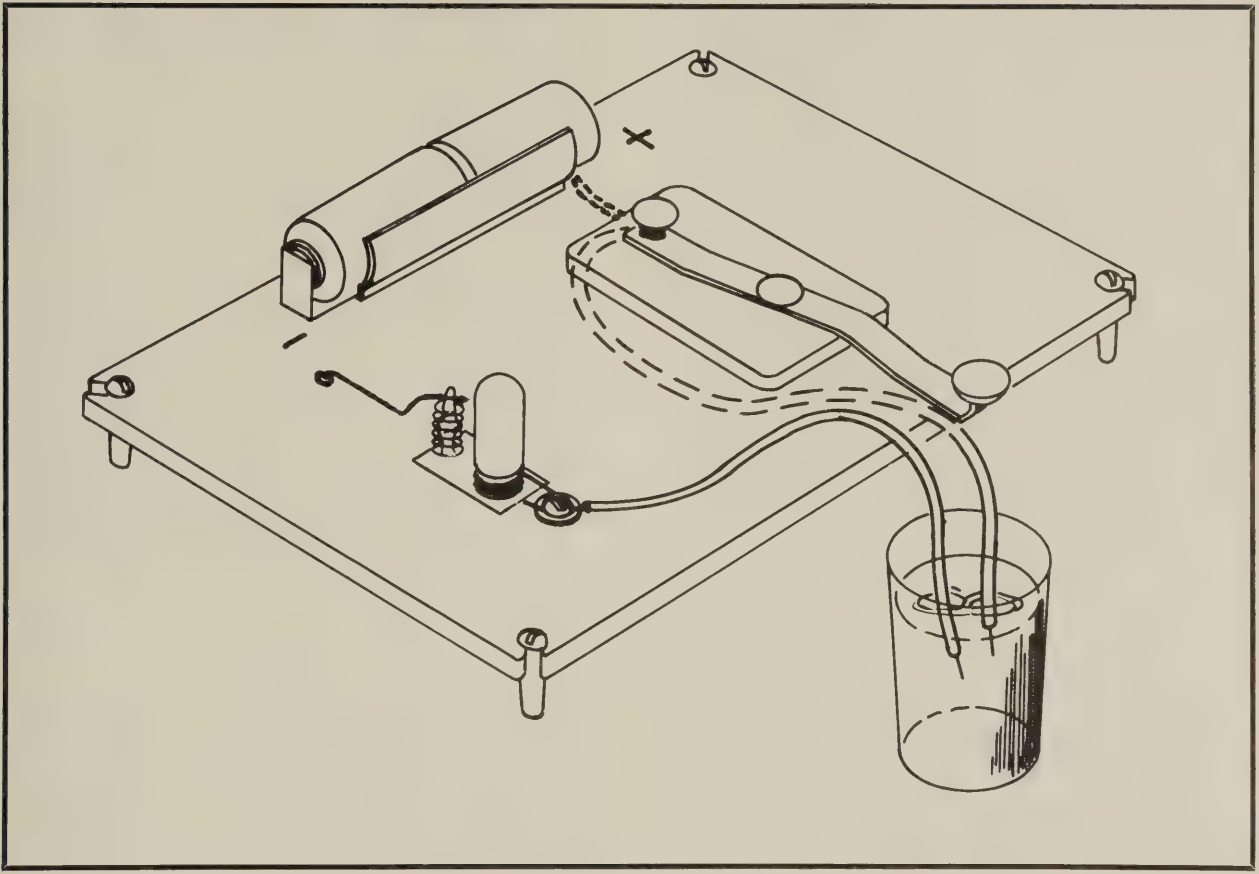


FIG. NO. 24

Attach one blue wire to [8-J] and the other to [14-E] with the circuit board set up as in *Fig. No. 24.* Fill a cup or glass with water to about half an inch from the top. Hold ends of the two wires in the water as shown and bring them slowly together — as close as you can without touching them to each other.

No matter how close you bring the wires, you will not see the bulb light at all until you actually touch the two wires.

Take the wires out of the water. Add two heaping teaspoonfuls of ordinary table salt and stir for a minute or two. Put the wires back into the glass about two inches apart and slowly bring them together as before. You should see the bulb light faintly, then become brighter as the wires move together, and then increase suddenly in brightness as the wires actually touch.

What does this experiment show? It may seem that water does not conduct electricity, but that salt does. Let us test this. Put two or three teaspoonfuls of salt in a little heap on a dry plate. Dry the ends of the wires carefully, then insert them in the pile of salt, very close together but not quite touching each other.

Notice that the bulb does not light until you actually touch the wires together. What does this mean? It means that dry salt does not conduct electricity well. But a solution of salt in water conducts electricity.

Here is the explanation. Ordinary table salt is described by chemists as the compound sodium chloride. It is composed of two elements, sodium and chlorine. The sodium atom has a charge of $+11$ on the nucleus, which is exactly balanced by 11 electrons. The chlorine atom has a charge of $+17$ on its nucleus, and 17 electrons.

If you bring a sodium and a chlorine atom together, the sodium atom will give up one electron to the chlorine atom. This leaves the sodium with a charge of $+1$. The chlorine atom, with its extra electron has a charge of -1. These charged atoms are called *ions.*

Since the two ions have opposite charges. they attract each other. Ordinary, solid sodium chloride is composed entirely of sodium and chlorine ions, bound tightly together by their electric attraction, to form what is known as a *crystal lattice*. Since there are exactly as many sodium ions as chlorine ions, the electric charge is exactly balanced and the sodium chloride crystal as a whole is electrically neutral.

Solid, dry sodium chloride does not conduct electric current because the sodium and chlorine ions are held tightly in the crystal lattice and cannot move. But if salt is dissolved in water, the sodium and chlorine ions are not held together. Now they are free to move — the positive sodium ions are attracted to the negative wire, the negative chlorine ions to the positive wire. That is why a salt solution conducts electricity.

Now wash the glass and the wire ends thoroughly to remove the salt. Again fill the glass with fresh water. Test to make sure the water does not conduct enough electricity to light the bulb.

Now add two heaping teaspoonfuls of sugar, stir for a minute or two, and test the same way as you did before. Notice that the bulb doesn't light at all until the wires actually touch each other.

Why doesn't the sugar solution conduct electricity? Because the crystal lattice of sugar is made up, not of ions, but of neutral sugar molecules — a combination of all the different elements that make up a sugar particle. When sugar is dissolved in water, these neutral molecules move around separately in the solution, but since they are electrically neutral, they do not move to the wires or conduct electricity.

PART 6

MAGNETISM

In the next five experiments you will become acquainted with magnets and magnetism. Like many boys and girls, you may have experimented with magnets already. Now you will learn many new and surprising things about them.

Magnets have been known for more than 2000 years. The ancient Greeks knew of stones that attracted iron. Until a short time ago, however, they were a complete mystery. No one knew where magnetism came from. Now we know — and the answer will surprise you. *Magnetism is caused by electricity.*

Any time an electric charge moves, it produces magnetism. Does this mean that the wire in one of your circuits becomes a magnet when electrons flow through it? Yes, it does. The magnetism is too weak to be detected without special instruments, but the magnetism is there all the same.

What about permanent magnets, like the magnets in your kit? These involve moving electrons, too — though not electrons flowing through a wire as in an electric current. Scientists have discovered that materials like iron become magnets because electrons move about in a special way inside the atoms of which the material is composed.

You will learn more about this shortly. Now, let's do experiments.

Experiment 13.

MAGNETS AND COMPASSES

Here are four rules you should follow in experiments with magnets:

1. Unless your watch is non-magnetic, keep it off while you work with magnets.

2. Don't bring a magnet too close to the compass. Otherwise, it may damage the compass.

3. When putting your magnets away, line them up so that they stick to each other. This will make them last longer.

4. Keep any magnet not needed in a magnetism experiment out of the way to prevent it from interfering with your experiment. Also, work at least a few feet away from radiators, stoves, and other large iron or steel articles that may be at least partly magnetized.

Now examine the two magnets. Notice as you touch them together in different ways, that they sometimes seem to attract, and sometimes seem to repel each other. See what household articles and materials they attract.

Tie a thread about 12 inches long around one magnet, as close to the center as you can. Hang the magnet in the air as you did the pith balls. Let the suspended magnet come to rest. Which way is it pointing?

It should point roughly north and south. The magnet turns into this direction because the earth itself is a magnet — a gigantic bar magnet with ends in the Arctic and Antarctic. Because the suspended magnet can turn very easily, it lines up with the earth's magnetic field, just as one magnet lined up with the other in the experiment you just did. The suspended magnet acts just like a compass.

Examine the compass furnished in the kit. The needle is a very light bar magnet on a pivot that allows it to turn easily. The blue end is called the *north pole* because it points almost due north to the earth's magnetic pole, which is located near, but not exactly at, the North Pole.

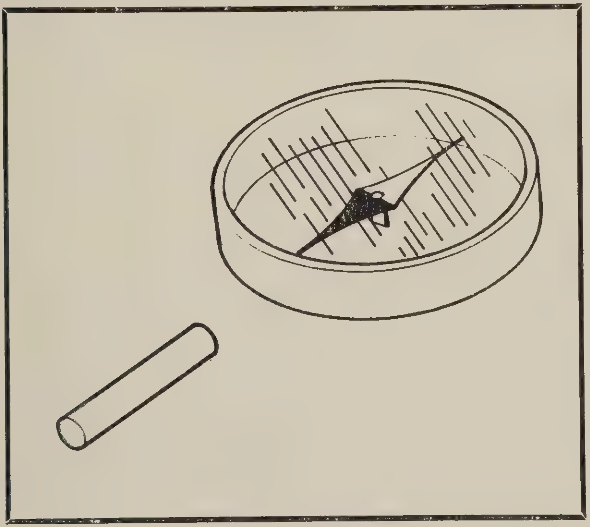


FIG. NO. 25

Notice the numbers on the compass. It is customary to divide the compass circle into 360 equal parts called degrees. North is 0 degrees; east, 90; south, 180; and west, 270. Degrees allow us to give directions more accurately.

Hold the compass three feet from the suspended bar magnet. The end of the magnet pointing in the same direction as the blue end of the needle must be a north pole. Write an *N* on it in pencil. The other end must be a south pole. Write an *S* there. Test and mark the other magnet in the same way.

Remove the thread-suspended magnet and test both magnets by touching them together in different ways as you did before. You will find that two north poles repel each other, and the two south poles repel each other. A north and a south pole, however, attract each other. In other words, *like magnetic poles repel each other, unlike poles attract each other.* This is just what you found with electric charges: *like* charges repel; *unlike* charges attract.

Can you see how to use your compass to tell which end of a magnet is which? Lay one magnet on the table. Bring your compass two or three inches from the magnet, as in *Fig. No. 25.* Which end of the compass points toward which end of the magnet?

Make sure you can do this test correctly, because you will need it in later experiments.

Now here is a question for you to think about. Is the earth's North Magnetic Pole a north pole or a south pole? Think it over. You may be surprised at your answer.

Experiment 14.
OBSERVING MAGNETIC FIELDS

Place one of your magnets on its side at the center of a sheet of writing paper. Trace a line around the magnet with a pencil.

Set your compass on the paper 1½ inches from the magnet. Make two dots on the paper showing the direction in which the needle is pointing. *(See Fig. No. 26.)* Then take the compass away and draw a line connecting the dots. The line records the direction of the magnetic force at that point.

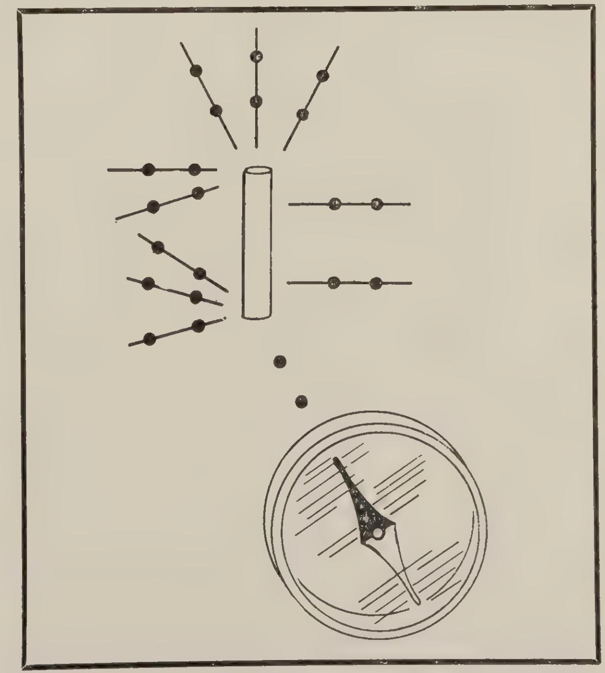


FIG. NO. 26

Do the same thing with the compass at several different positions all around the magnet. You should get a picture on the paper like that in *Fig. No. 27.*

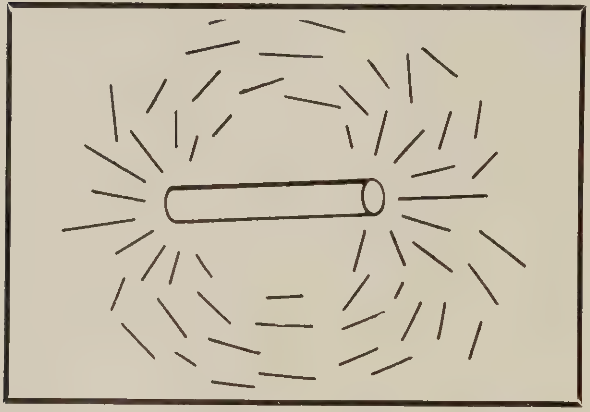


FIG. NO. 27

If you had a compass with a very short needle, and if you could put it above and below the paper and draw lines in the air, you would obtain a pattern like that in *Fig. No. 28.* These lines are called *magnetic lines of force.* They give us a model of the *magnetic field* or magnetic force around the magnet. The lines have been drawn closer together in the places where the magnetic field is strongest. So they tell us not only the direction but also the strength of the magnetic force around a magnet. Notice that the two poles are simply places where the magnetic force is strongest (where the lines of force are closest together).

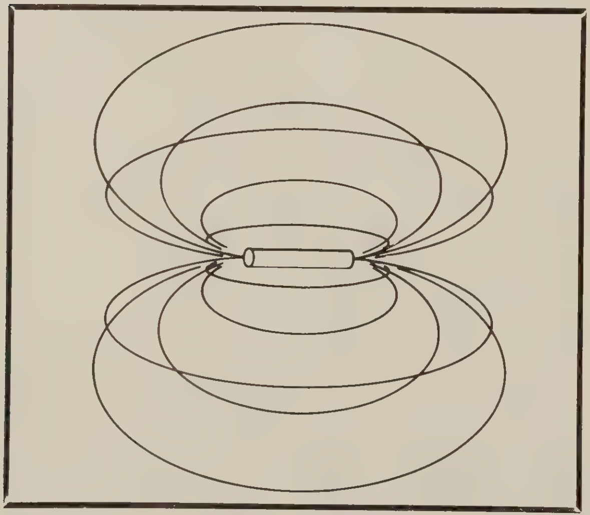


FIG. NO. 28

Of course, the lines of force are only a model. There is also magnetic force in between the lines of force shown in *Fig. No. 28.*

A simple way to map out these imaginary lines is to use iron powder. As you will see, the fine particles of iron will line themselves up like tiny compass needles.

Lay a magnet inside the kit cover or other large box (to catch any iron powder you may spill). Place the plastic insert sheet over it, resting on the magnet. Carefully sprinkle a little iron powder over the magnet and the area around it, from about 8 inches above the magnet. *Don't use up too much powder.* Use just enough to show a pattern. Notice how much this pattern resembles *Fig. No. 27.*

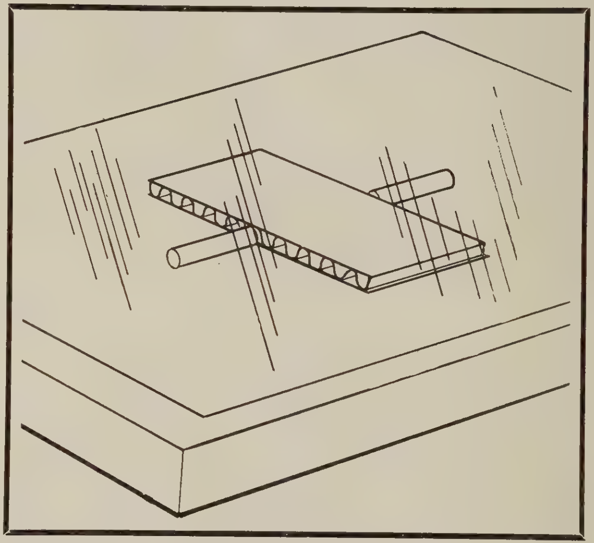


FIG. NO. 29

Now let us observe lines of force when two magnets are attracting each other. To do this, we must find a way to hold the magnets half to three-quarters of an inch apart. Cut a strip of cardboard a half inch wide. Place it on your work table. Place the magnets on either side of it with unlike poles pointing together, as in *Fig. No. 29.*

Set the plastic insert sheet over the magnets and sprinkle iron filings on the sheet as you did before. Study the pattern you obtain. Notice that some of the lines pass out of one magnet and enter the other. *(See Fig. No. 30A.)*

Next, study the pattern of a repulsion field. This time you don't need the cardboard separator. Place the magnets about an inch apart with two *like* ends pointed toward each other. Place the insert sheet over the magnets and sprinkle with iron powder.

Notice that the pattern you now obtain is quite different from that of an attraction field. In the space between the magnets the lines of force run side by side instead of passing from one magnet to the other. *(See Fig. No. 30B.)*

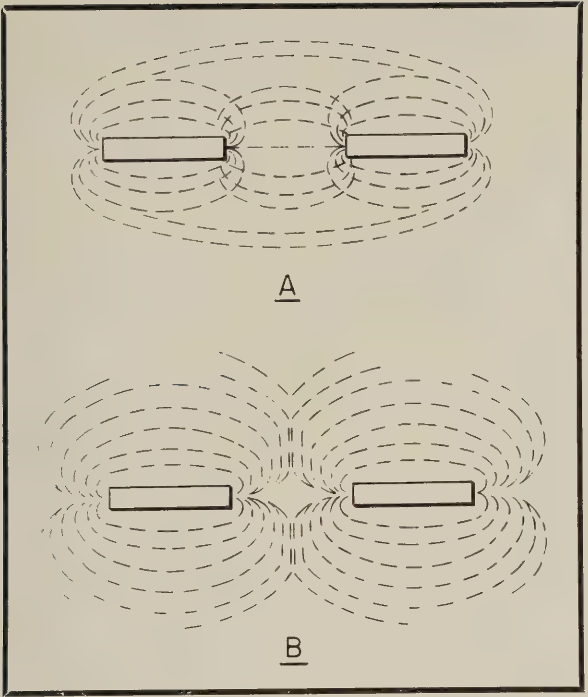


FIG. NO. 30

Experiment 15.

WHAT CAUSES MAGNETISM?

As you have read, magnetism is caused by moving electric charges—usually electrons.

In fact, each electron is itself a tiny magnet because electrons spin. Scientists have been able to prove this with the aid of special laboratory equipment. We can think of an electron as spinning somewhat as a top spins, or as the earth rotates on its axis. This spin produces magnetism.

Electrons revolve around the nuclei of atoms like artificial satellites around the earth. This motion also causes magnetism. *(See Fig. No. 31)*. However, their spin is much more important. In your bar magnets, for example, more than 90% of the magnetism comes from electron spin, and less than 10% from motion around the nucleus.

At this point you may be wondering why everything in the world isn't a magnet, since moving electrons are everywhere.

This experiment will give you the answer. Clear all components from your breadboard. Leave the batteries, battery holder and code key (which you will need in later experiments). Put the battery terminal wires out of the way. Make sure that the battery wires do not touch each other.

Set the compass on the breadboard with its center directly over hole [N-4] and with the "N" pointing directly toward hole [H-4]. Turn the board so that the north end of the needle points to the "N" on the compass card.

Lay one of the magnets on the board with the south pole over hole [15-N] and its north pole over hole [17-N]. The compass needle will turn a number of degrees toward the east. Notice that the earth's magnetic field is pulling the needle one way, and the magnet is pulling it another. The weaker the pull of the magnet, the less the needle will be pulled from north. The stronger the magnet, the more it will be pulled toward the east.

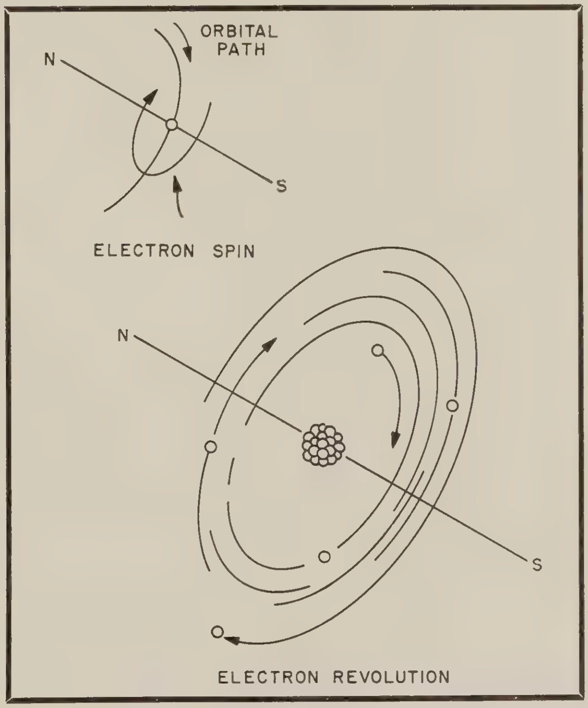


FIG. NO. 31

Hold the magnet in place with your finger, and bring the other magnet alongside it, with both the south poles on [15-N] and both the north poles on [17-N]. Notice that this increases the effect of the magnets on the compass needle, pulling it farther to the east.

Now keep the first magnet as it was, and turn the second magnet around, so that a north pole and a south pole are over hole [15-N], and a north pole and a south pole are over [17-N]. Notice that now the two magnets have almost no effect on the compass needle. And also notice that it is much easier to line up the magnets in this way, with their fields canceling each other, than it was to arrange them the other way with their fields adding up.

This illustrates why most materials are not magnetic. In most substances, the atoms are so arranged that there are an even number of electrons, with the electrons in pairs, like the two magnets. As a result, the magnetic fields of the electrons cancel out, and the material is nonmagnetic. *(See Fig. No. 32.)*

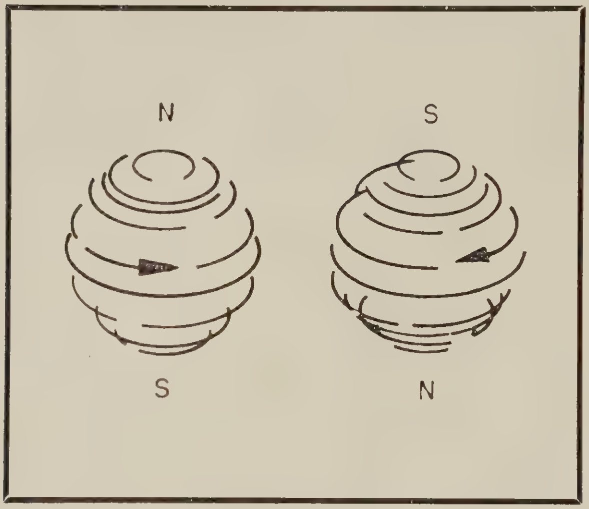


FIG. NO. 32

In a much smaller number of substances, there are one, two, or sometimes three or more unpaired electrons in each molecule (group of atoms). Most of these substances are only very weakly magnetic because the molecules arrange themselves in such a way that they cancel out most of each other's magnetism. These are called *paramagnetic* substances.

Finally, there are some substances in which there is a strong tendency for the atoms and molecules to be arranged with their magnetic fields all lined up in the same direction so that the effects add together. These substances are strongly magnetic, thousands of times more magnetic than paramagnetic substances. Iron is an outstanding example of this kind of material. Therefore materials of this sort are called *ferromagnetic*, from the Latin word *ferrum*, meaning iron.

Experiment 16.

MAKING A MAGNET

Lay a magnet and the iron rod on your work table end to end, with one end of the rod against the north pole of the magnet. Cover them with the plastic insert sheet, and sprinkle with iron powder. Tap the plastic sheet gently with your finger to help the particles of powder jump into a clearer pattern.

The pattern shows the strong magnet. In addition, around the iron rod there is a similar though weaker pattern. Remove the plastic sheet without moving either the rod or the magnet, and test with the compass to see what kind of pole is at the end of the rod away from the magnet.

Now what kind of pole must be on the end of the rod touching the north pole of the magnet? Since it is attracted by a north pole, it must be a south pole.

Thus you have turned the iron rod into a magnet. What happens is this: When you bring a piece of iron into a strong magnetic field, many of the unpaired electrons in the iron line up as in a magnet. *(See Fig. No. 33.)*

And this is what always happens when a magnet attracts something. A magnet attracts only another magnet. When a magnet attracts an article, it first turns it into a magnet. This is very similar to an effect you saw in Experiment 5. When the static electricity charge attracted the bits of tissue paper, it did so by causing electrons to move in such a way as to produce electric charges on the surface of the bits of paper.

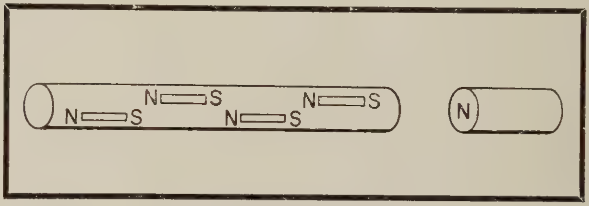


FIG. NO. 33

Ferromagnetic materials are attracted strongly by a magnet because they are easily magnetized. On the other hand, it is difficult to magnetize paramagnetic materials strongly. They are therefore attracted very weakly.

What happens when you remove a ferromagnetic material from a magnetic field? If it is soft iron, it usually loses most of its magnetism quickly. Hence soft iron is used to make *temporary magnets*. But hard materials such as hardened steel tend to retain magnetism. They form *permanent magnets*.

Remove the magnet from the rod, and test the rod with the compass. Even though it is made of soft iron, you may find that it retains a little magnetization.

Now that you understand that a magnet attracts by magnetizing, you can understand why particles of iron powder group themselves in lines. Each particle becomes a little magnet with its poles in line with the field. These tiny magnets attract each other end to end, to form the long chains that you saw on the plastic sheet.

Experiment 17.

MAKING AN ELECTROMAGNET

Take the smaller of the two coils of copper wire. Be careful not to kink the copper wire, or you may break the thin layer of plastic insulation covering the wire.

Mark one end of the coil form. Hold this end of the form toward you, and start winding the wire around it in a *clockwise* direction. *(See Fig. No. 34.)* Wind the wire rather tightly, and as neatly as you can.

When you are a quarter inch from the unmarked end, start winding a second layer back toward the marked end. Keep winding in the same direction. If the wire slips, you may want to fasten the ends with cellophane tape.

You have made a type of electromagnet. To test it, set up the circuit shown in *Fig. No. 35.*

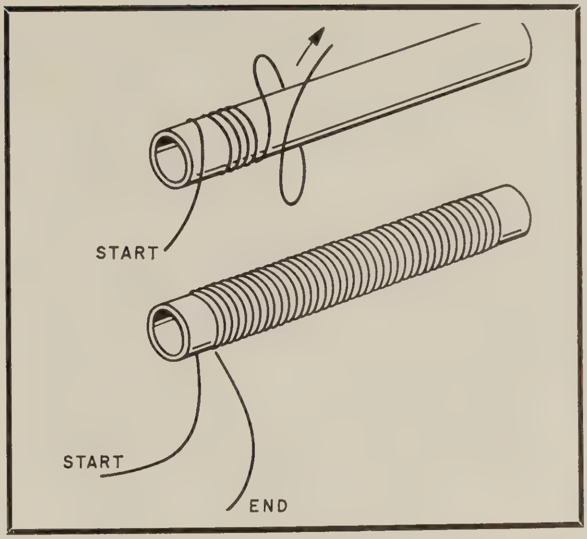


FIG. NO. 34

Put connectors in holes [8-J] and [8-G]. The electromagnet is placed with the marked end over hole [4-G], and the unmarked end over hole [4-K]. If necessary, fasten it in place with a piece of cellophane tape.

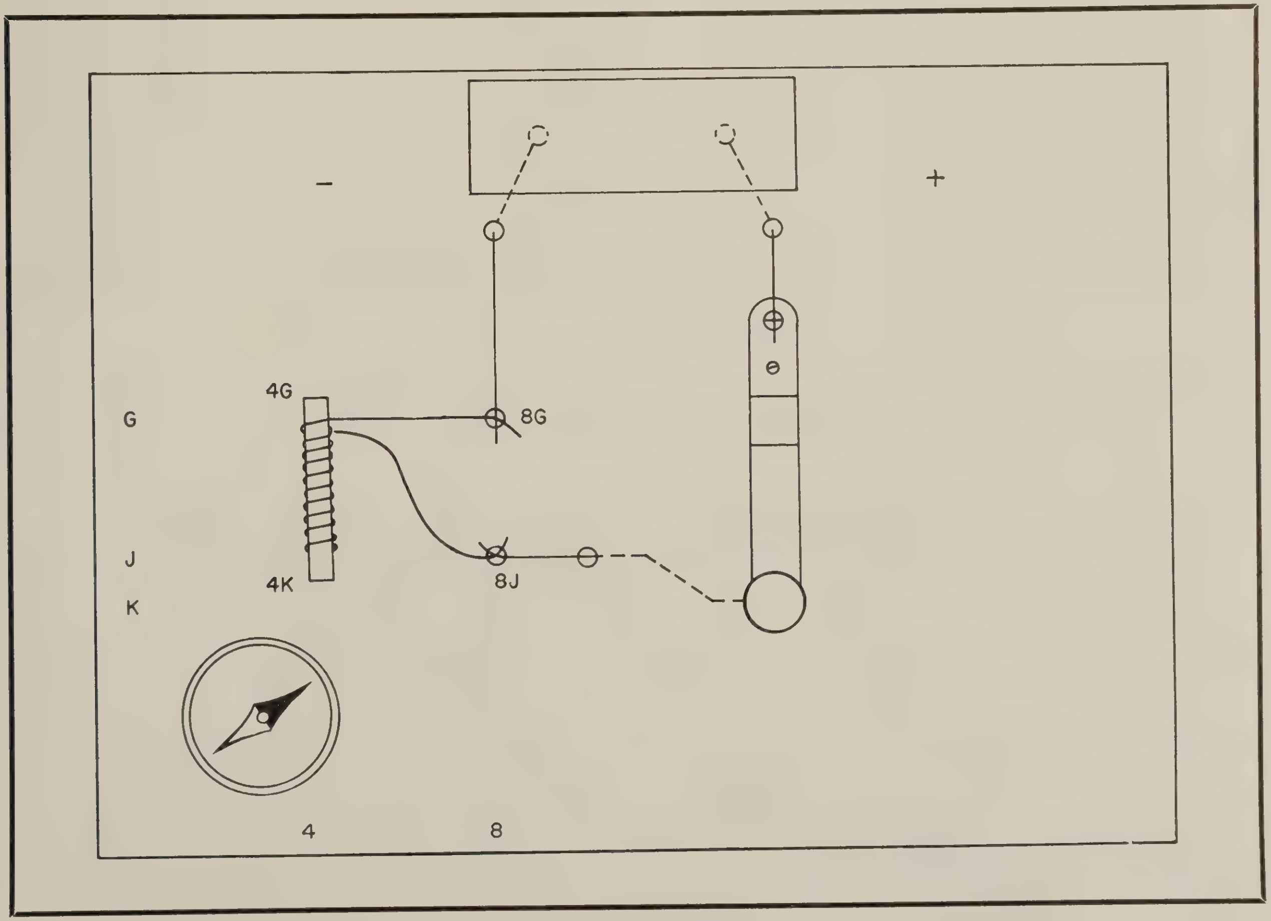


FIG. NO. 35

Use the code key as a switch. Do not leave your electromagnet on more than a few seconds, or you will soon need a new battery.

Imagine you are looking toward the electromagnet from hole [4-N]. Then the flow of electrons through the coil will be in a clockwise direction from your point of view.

Set your compass on the breadboard with its center over hole [4-N], as in *Fig. No. 35.* Turn the compass so that the "N" points toward hole [8-J]. Now turn the whole breadboard until the north end of the needle is on the "N".

Press the code key and hold the circuit closed for only about 3 seconds. What does the compass do? What kind of pole is at the marked end of the electromagnet?

Now look back at *Fig. No. 32* on Page 24. Notice the relation between the direction of electron spin and the north pole of the electron. In your electromagnet, do you have the same relation between the direction in which the electrons are going around the coil, and the position of the north pole?

What will happen if you reverse the direction of the current in the electromagnet? Try it and see. Turn the batteries around in their holder, but make sure that they make contact.

What happens?

The electromagnet you have made is called an *air-core* magnet, or a *solenoid.* It is a very weak magnet, but you can easily make a stronger one.

Change your batteries back. Press the key for several seconds, and notice how many degrees the compass needle moves from north. If the needle keeps swinging back and forth, watch it for about 10 seconds and try to estimate where it would finally come to rest if you could wait that long.

Now put the iron rod inside the coil form. How far does the compass turn from north now?

With the iron core, your electromagnet is strong enough so that you should be able to set up a good iron powder pattern. Place the plastic sheet over the electromagnet and try it. But be careful to hold the key down only while you sprinkle the powder. At the end, hold down the key once more, and gently tap the plastic insert.

Notice that the pattern is exactly the kind you obtain with a bar magnet. If you had more powerful batteries, you would see that the air-core magnet also gives the same type of pattern. And this is what should be expected—since the air-core magnet and the bar magnet both depend upon the same motion of electrons to cause their magnetism.

Why does the iron core strengthen the magnet? Because the weak magnetic field of the solenoid caused some of the unpaired electrons in the iron to line up with the solenoid field. So the field is greatly strengthened by the added magnetism of the iron.

Now you are ready to learn something new and really remarkable about magnetism. Read "How Moving Electrons Cause Magnetism".

HOW MOVING ELECTRONS CAUSE MAGNETISM

In the last experiment, you saw that moving electrons, an electric current can produce magnetism. We have also seen that the magnetism of a permanent magnet is also due to moving electrons—in this case, mostly the spin of electrons on axes.

How moving electrons produce magnetism is exceedingly interesting.

The answer is exceedingly interesting.

Imagine that you have two 10-inch lengths of copper wire side-by-side a few inches apart. Now imagine that you can take the wires apart, atom by atom and electron by electron, in some magical way to obtain a clear look at how they act on each other.

First of all, remove all the free electrons from each piece of wire and line them up outside each wire, leaving nothing but positively charged atoms in the wires. Although the force exerted by a single electron is tiny, there are so many atoms and free electrons in the 10-inch pieces of wire that the forces of attraction and repulsion they can exert are enormous. The various pushes and pulls of the columns of electrons and positively-charged wires on each other each amount to a million tons!

Of course we don't ordinarily notice these stupendous forces because the electrons and positively-charged copper atoms are all together inside the wire and the attraction and repulsion forces exactly balance each other. However, if the charges are moving, there will be a tiny change in the attraction and repulsion so that they no longer balance exactly. And this is what causes magnetism. Let us see how this comes about.

What counts is the *relative motion*, the speed with which a charge is moving *in relation* to another charge. Here is what we mean by relative motion: If, for example, you're in a car going north at 60 miles an hour, and another car is driving right alongside you at the same speed, then your speed in relation to the other car is zero. You're not moving at all in relation to the second car. Suppose another car is driving south at 60 miles an hour. Your speed in relation to that car will be 60+60 or 120 miles an hour.

Now here's the basic physical law that causes magnetism: When one charge is moving in relation to another, the electric attraction or repulsion between ther is *increased*. The greater the relative speed, the more the forces are increased. If you double the relative speed, *extra* force is increased 4 times.

Now imagine that electrons are moving in both wires in the same direction. Since the positively-charged atoms aren't flowing, the two wires still repel each other with a force of 1,000,000 tons. Now how about the electrons? They are moving in relation to the protons, but they're not moving in relation to each other. So the repulsion between wires due to the free electrons is still 1,000,000 tons. The total repulsion is 2,000,000 tons.

Next, look at the attraction between the free electrons in one wire and the positive ions in the other. The electrons are moving relative to the positive ions, and the attraction is increased to 1,000,000 tons plus (let us say) 1 ounce. And since the electrons in each wire are attracting the positive ions in the other, the total attraction is 2,000,000 tons + 2 ounces. If we subtract the repulsion from the attraction, that leaves 2 ounces of attraction. Hence, the wires attract each other magnetically with a force of 2 ounces.

What would happen if the currents in the two wires were flowing in opposite directions? Since the speed of the electrons in one wire in relation to the electrons in the other wire is twice as great as the speed of the electrons in relation to the protons, there is extra repulsion between the electrons of 4 ounces. Thus the repulsion is greater than the attraction, and the two wires repel each other with a force of 2 ounces.

So magnetism is a result of relative motion of electric charges. And in talking about relative motion, we've been talking a bit of Einstein's theory of relativity. For that is what Einstein's theory has to do with — relative motion and the effects it can have. And we can say that magnetism is a relativity effect of moving electric charges.

PART 7

ELECTRICAL INSTRUMENTS

Back in Part 5 you learned something about electric circuits. But you could only make a start in your exploration of electricity because you had no way to measure the voltages and currents in your circuits except by making very rough estimates from the brightness of your light bulb. Now you are going to make an electrical measuring instrument called a *galvanometer*, and then you will use your galvanometer to make another instrument, a *voltmeter*. With these you will be able to measure what is happening in your circuits, and you will learn a great deal more about electric circuits. Also, you will learn something about the types of measuring instruments used by scientists and engineers in working with electricity.

A galvanometer, like many other electrical instruments, works by means of electromagnetism. That's why you did not build a galvanometer earlier; but now you've learned quite a lot about magnetism and you're well prepared to make a galvanometer.

In fact, you will find that what you did in the last experiment was good practice for this — because the first thing you have to do now is wind another coil.

Experiment 18.

MAKING A GALVANOMETER

Find the galvanometer frame and bend it as in *Fig. No. 36.*

Wind your remaining coil of copper wire wire around the frame, catching the wire in the slots in the support. Start winding about 4 inches from one end of the wire and leave at least 4 inches at the other end. Twist the two ends of the wire together twice to hold the coil in place. (*See Fig. No. 36*) CAUTION: Don't twist too hard or you will damage the insulation or break the wire.

What you have made is an air-core electromagnet. Now put your compass inside it, with the wire above and below it — and you have a galvanometer.

You must mount your galvanometer on the breadboard so that the wire of the coil is pointing exactly north and south. This means that you will have to turn the breadboard as you did before. Remove the electromagnet from the last experiment.

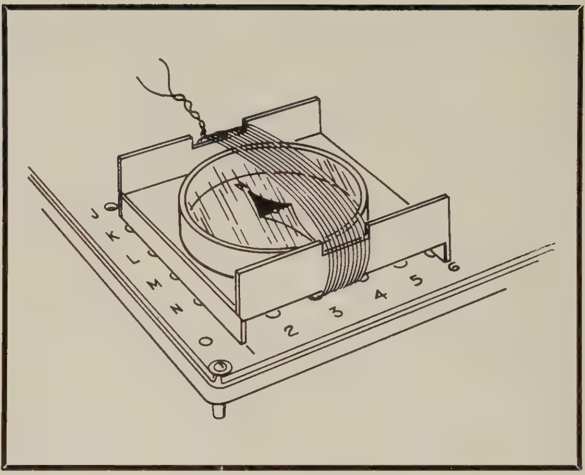


FIG. NO. 36

Place a spring connector in hole [4-H]. Attach the 100-ohm resistor between [8-G] and [4-H]. Mount the galvanometer as in *Fig. No. 37*. Attach one wire to [4-H] and the other to [8-J].

Turn the breadboard until the wires of the coil are exactly in line with the needle, as in the illustration. Turn the compass so that the

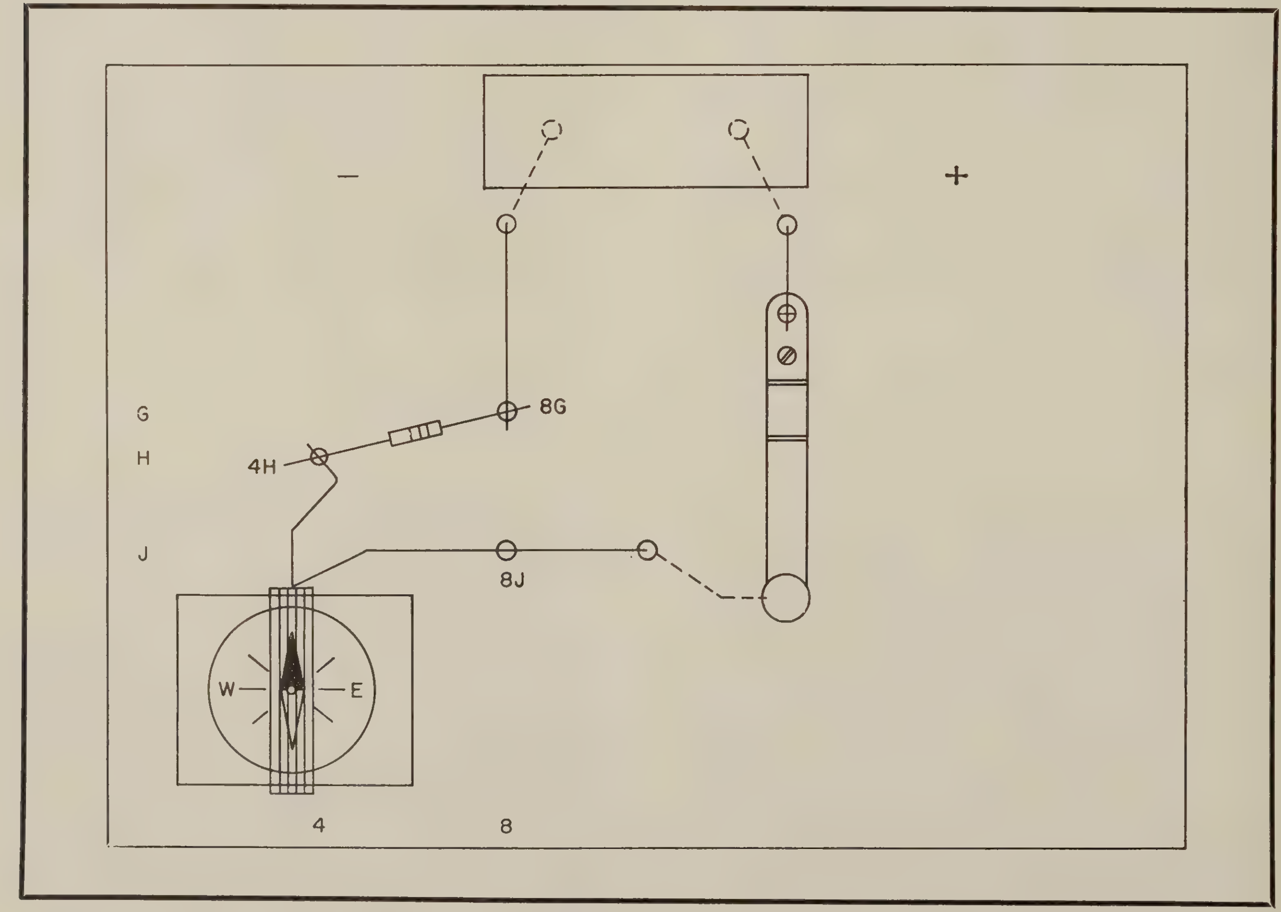


FIG. NO. 37

"N" is under the north end of the needle. Center the compass exactly in the center of the support.

Press the code key. What does the compass read? How many degrees has the needle moved from north, and did it move clockwise or counter-clockwise?

This is how your galvanometer works. When no current is flowing through the coil, the compass needle points toward the earth's North Magnetic Pole. When you turn on the current, the electromagnet produces a new magnetic field, directed at right angles to the earth's magnetic field. Therefore, the needle swings to a position in between the direction of the earth's field and the galvanometer field. *(See Fig. No. 38.)*

What will happen if you reverse the direction of the current through the galvanometer? Try it and see. Reverse the galvanometer wires attached to connector [4-H] and to connector [8-J]. Does the needle move as far in one direction as it did in the other?

What does a galvanometer measure — voltage, current, resistance, or what? The answer is: it measures current. The more the current flowing through the coil, the stronger the magnetic field will be and the farther the needle will turn.

A resistor with a resistance of 100 ohms is connected in series with the galvanometer. The galvanometer coil has very low resistance, less than an ohm. Therefore, assume the total resistance in the circuit is 100 ohms. Since you are using two batteries, the voltage is 3 volts. According to Ohm's law:

Current in amperes =
3 ÷ 100 = 0.030 amperes.

How many degrees does this make the needle move?

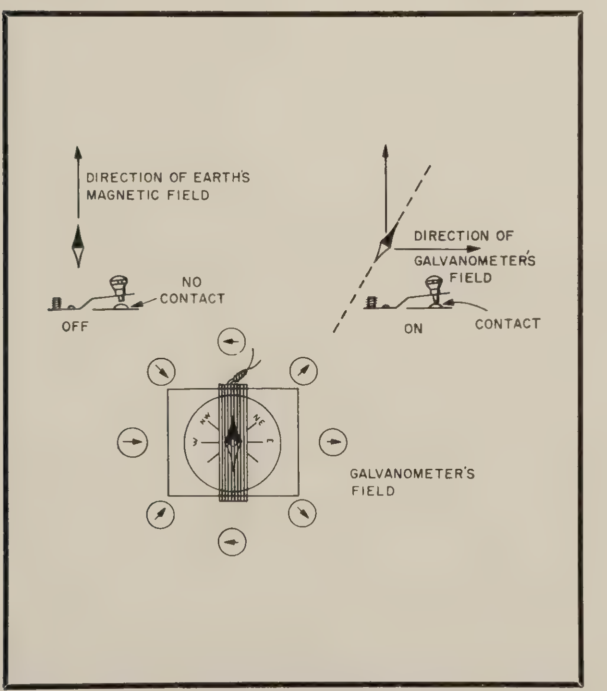

DIRECTION OF EARTH'S MAGNETIC FIELD
NO CONTACT
OFF
DIRECTION OF GALVANOMETER'S FIELD
ON
CONTACT
GALVANOMETER'S FIELD

FIG. NO. 38

Experiment 19.
MEASURING CURRENT WITH A GALVANOMETER

Leave your breadboard setup as in *Fig. No. 37.*

Mount the lamp and holder between [8-G] and [4-G]. You will have to put a connector in hole [4-G], also in [2-H]. Remove the galvanometer lead from [4-H] and insert it in [2-H]. Leave resistor lead attached to [4-H]. The circuit is shown in *Fig. No. 39A.*

In this experiment, you will measure the current in each of the "arms" of a parallel circuit (the bulb and the resistor) and the current flowing from the battery. You will prove that the current from the battery equals the sum of the currents in the two parallel arms.

First, connect a green wire from [4-G] to [2-H] and a blue one from [4-H] to [8-J]. This circuit is shown in *Fig. No. 39B.* The galvanometer is now measuring the current flowing through the bulb.

Make a note of the reading when you press the key — let us say, 45. Now remove the green wire from [4-G] and move it to [4-H]. Move the blue wire from [4-H] to [4-G], as in the circuit in *Fig. No. 39C.* Here you are measuring the current flowing through the resistor. Note the reading — for instance, 15.

Now for the third step. Shift the green wire from [2-H] to [4-G], and the blue wire from [8-J] to [2-H]. When you press the key, you will measure the total current from the battery, as in *Fig. No. 39D.* Note the reading — say, 60. This reading should be equal to the sum of the first two readings:

15 + 45 = 60.

Add together the readings you actually got for the current through the resistance and the current through the bulb. The total would be exactly the same as you found for the total current from the battery in the third measurement if your galvanometer were perfectly accurate. Actually, it is fairly acurate for measuring currents small enough to give compass readings of 20 to 30 degrees. Currents that give larger readings are not accurately measured.

This is not the fault of your galvanometer. No galvanometer can measure all currents accurately. All are accurate only when the compass needle is not deflected too much.

Engineers use different galvanometers, with different coils, for large currents and small currents. Yours is designed to give good readings in circuits like the one in this experiment. And you put a 100-ohm resistor in the circuit to make sure the current will be small enough so that your galvanometer will work well.

In this experiment you demonstrated Kirchhoff's current law, named after Gustav Kirchhoff, a German physicist who lived from 1824 to 1887. This law tells us that at any point in an electric circuit, if we add up all the current to that point and add up all the current flowing away, the two totals will be exactly equal. For example, in your experiment, you measured the current flowing in the three parts of the circuit. Kirchhoff's current law tells us that the curent flowing away from Point P is equal to the total current flowing into Point P through the two branches.

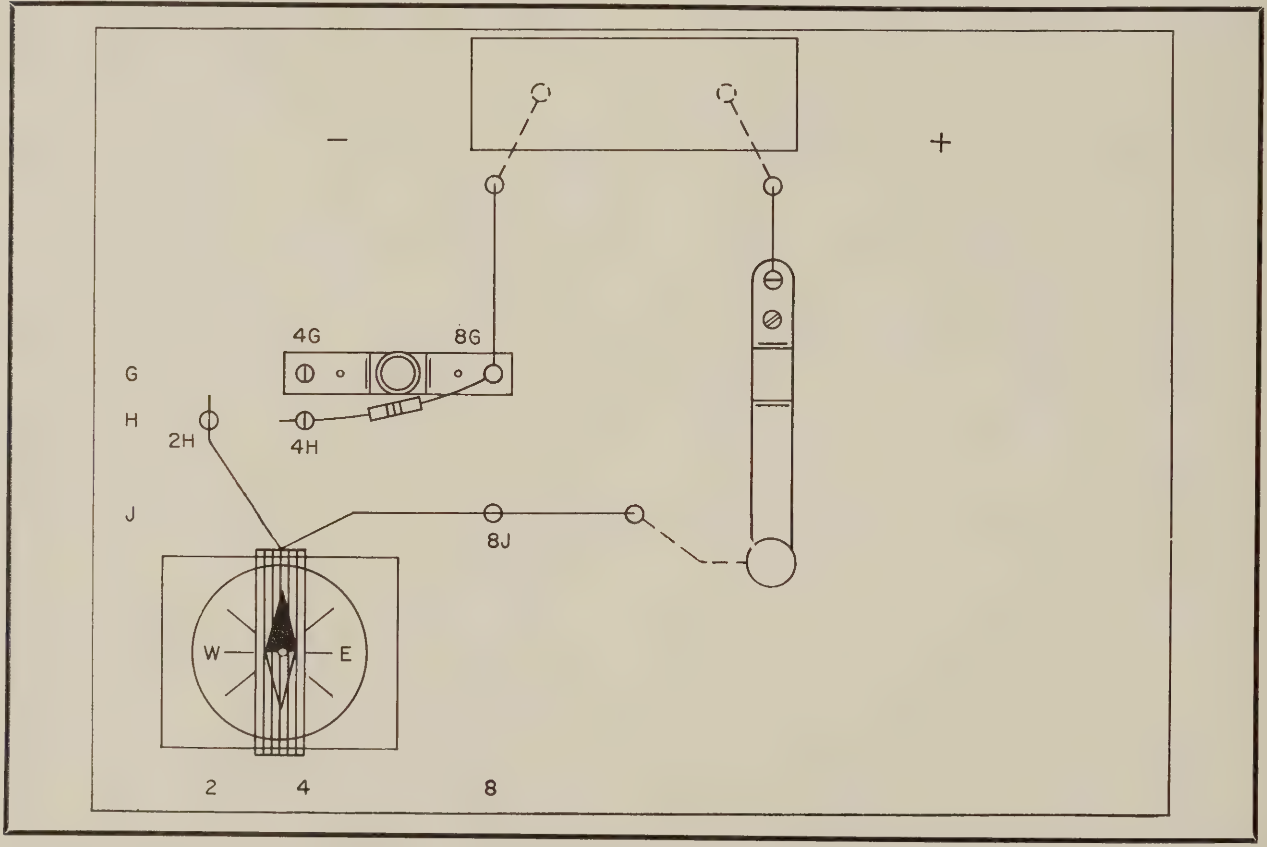


FIG. NO. 39

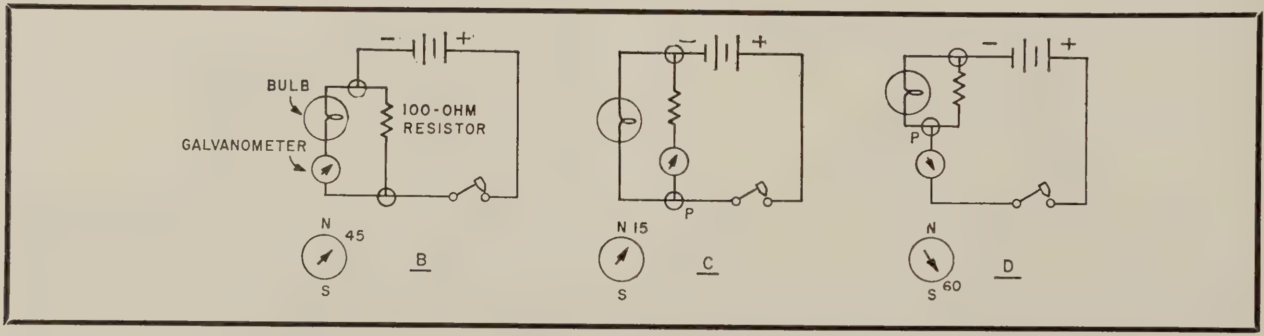


FIG. NO. 39A

Experiment 20. MAKING A VOLTMETER

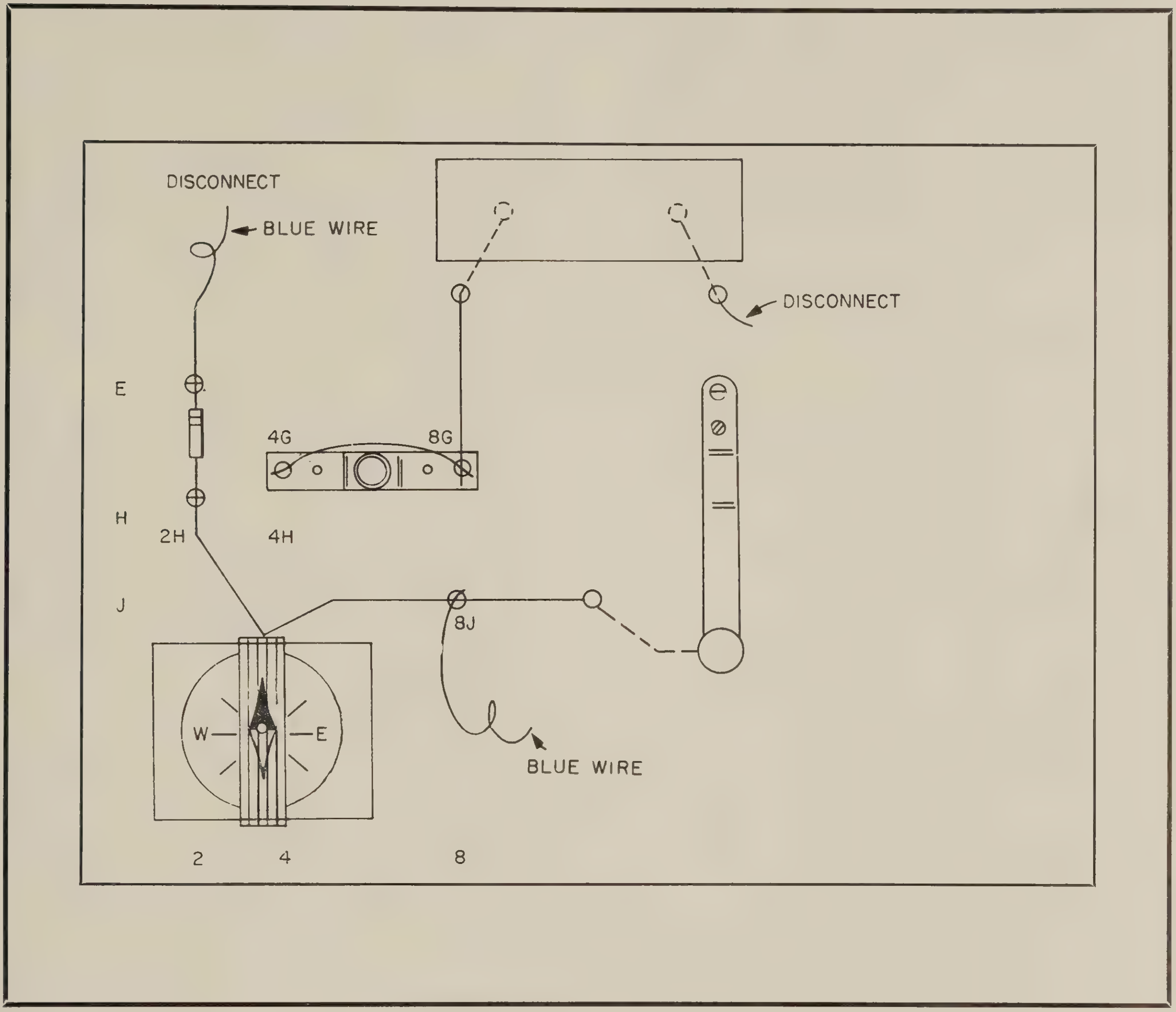


FIG. NO. 40

Set up the circuit board as shown in *Fig. No. 40.*

Insert a connector in [2-E]. Move the 100-ohm resistor to [2-E] and [2-H]. Attach one blue wire to [2-E] and another to [8-J]. These blue wires will be your test probes. Disconnect the positive battery lead from [14-E].

In the previous experiments, the resistor was put into the circuit to keep the current small enough to obtain accurate readings from the galvanometer. Now you will connect the galvanometer in *parallel* with the circuit and use it as a voltmeter. To make it useful as a voltmeter, however, there must be a resistance in series with the galvanometer itself. Notice this as you experiment. You will see why shortly.

Connect the two blue leads of your voltmeter across a single battery. What does your compass read? This is the reading of your voltmeter for 1.5 volts, the voltage of a single flashlight cell. Write it here in pencil. (__________).

Now connect the voltmeter across the two batteries in series. How many volts is this? Write the reading here. (______________).

Let's say that 1.5 volts gave you a reading of 15 degrees. And let's say that the reading you found for both batteries was 30 degrees. Since 15 is half of 30, this means that the voltage across the two batteries is twice 1.5 volts, or 3 volts.

Now measure the voltage between the positive battery terminal and [14-E]. *(See Fig. No. 41.)* The voltage reading should be approximately the same as the voltage of the two batteries. This is because the series resistance of the voltmeter prevents much current from flowing, and so there is very little voltage lost across the bulb.

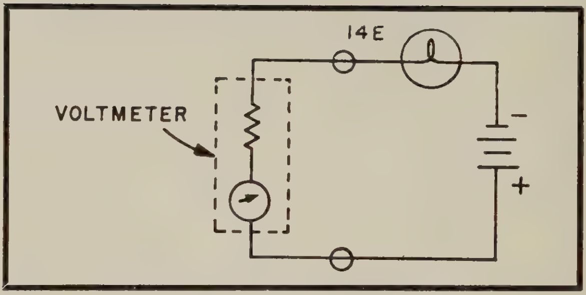


FIG. NO. 41

Experiment 21. THE VOLTMETER IN AN ACTIVE CIRCUIT

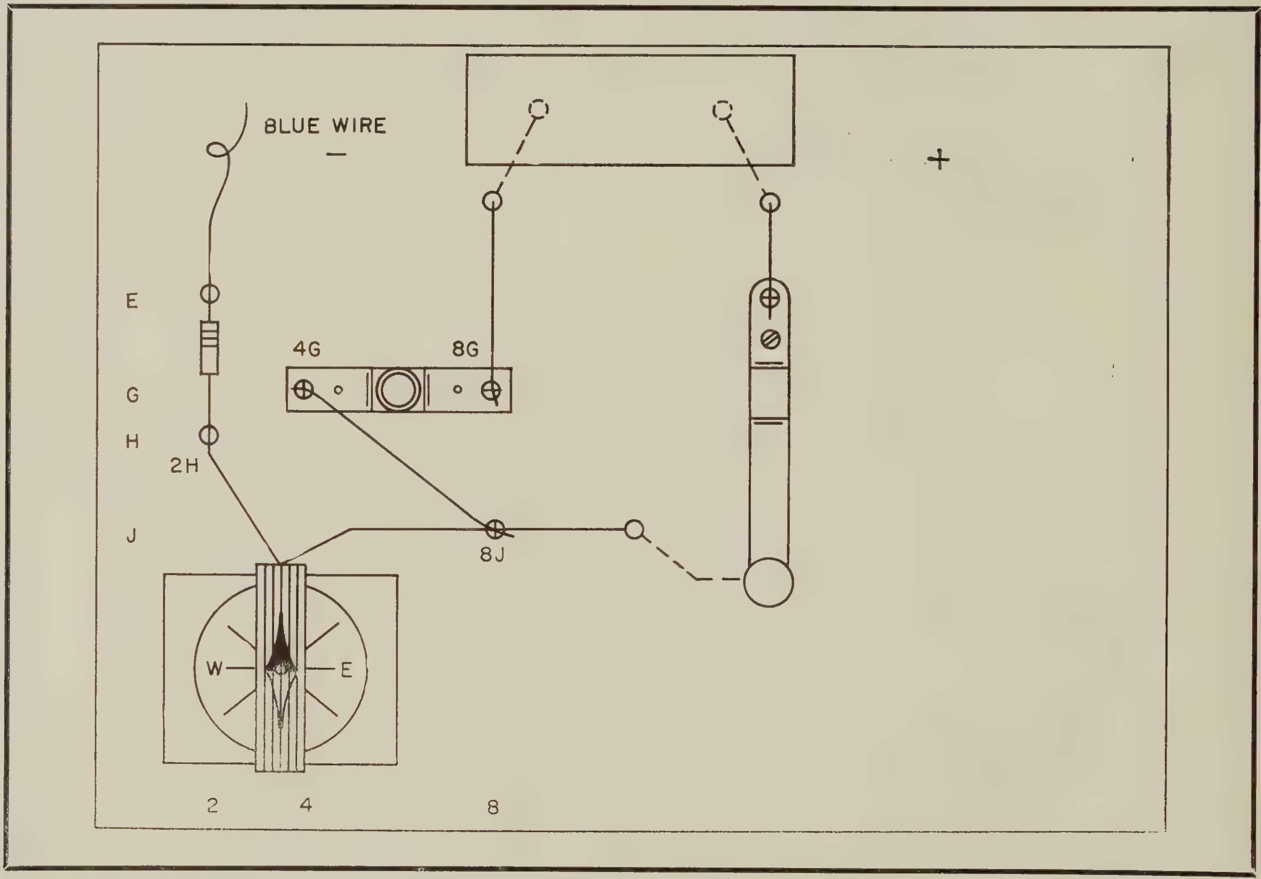


FIG. NO. 42

Now let us measure voltage in an active circuit. Reconnect the positive battery lead to [14-E]. Connect the free end of the blue wire attached to [8-J] to the bulb at [4-G]. The circuit should be set up as in *Fig. No. 42.*

Press the key. The bulb should light. Now touch the free end of the blue wire test probe to [4-J]. You are now measuring the voltage across the bulb, as in *Fig. No. 43.*

Does the bulb dim a little when you connect the voltmeter? It should dim very little. The voltmeter is drawing some current from the circuit, but not enough to interfere with its working.

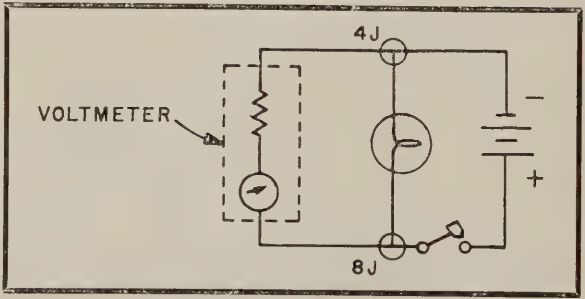


FIG. NO. 43

Now remove the blue wire test probe from [4-J] and [2-E]. Connect one end to [2-H]. The 100-ohm resistor is no longer in the circuit. Now, with the key pressed down, briefly touch the free end of the blue wire test probe to [4-J]. What happens to the bulb? The bulb goes out. The meter is interfering with the operation of the circuit.

Now you can see why you need the resistor in series with the galvanometer to make a voltmeter. The galvanometer coil is a low resistance wire. If you didn't have a resistor in series with it and you tried to use it as a voltmeter, it would short out anything you connected it across. And this would change the voltage in different parts of the circuit so that you wouldn't be reading true voltages any more.

For a galvanometer, then, you want a low resistance because you cannect it in the circuit in series. For a voltmeter, you want a high resistance because you connect it in parallel with part of the circuit.

PART 8

APPLIED ELECTRICITY

Now you've come to the best part of all.

In the next four experiments, you will use the parts in those two plastic bags that you've been saving so long.

The bell (Experiment 22) is fun to build, and you can also use it for learning Morse code (Experiment 23). But the most important thing you will get from building it is experience that will help you build the electric motor in Experiment 24.

After you have built the motor, you will try some interesting things with it (Experiment 25). Finally, at the end, you will learn something about how electric power is generated in power plants and carried into your home.

Experiment 22. MAKING A BELL

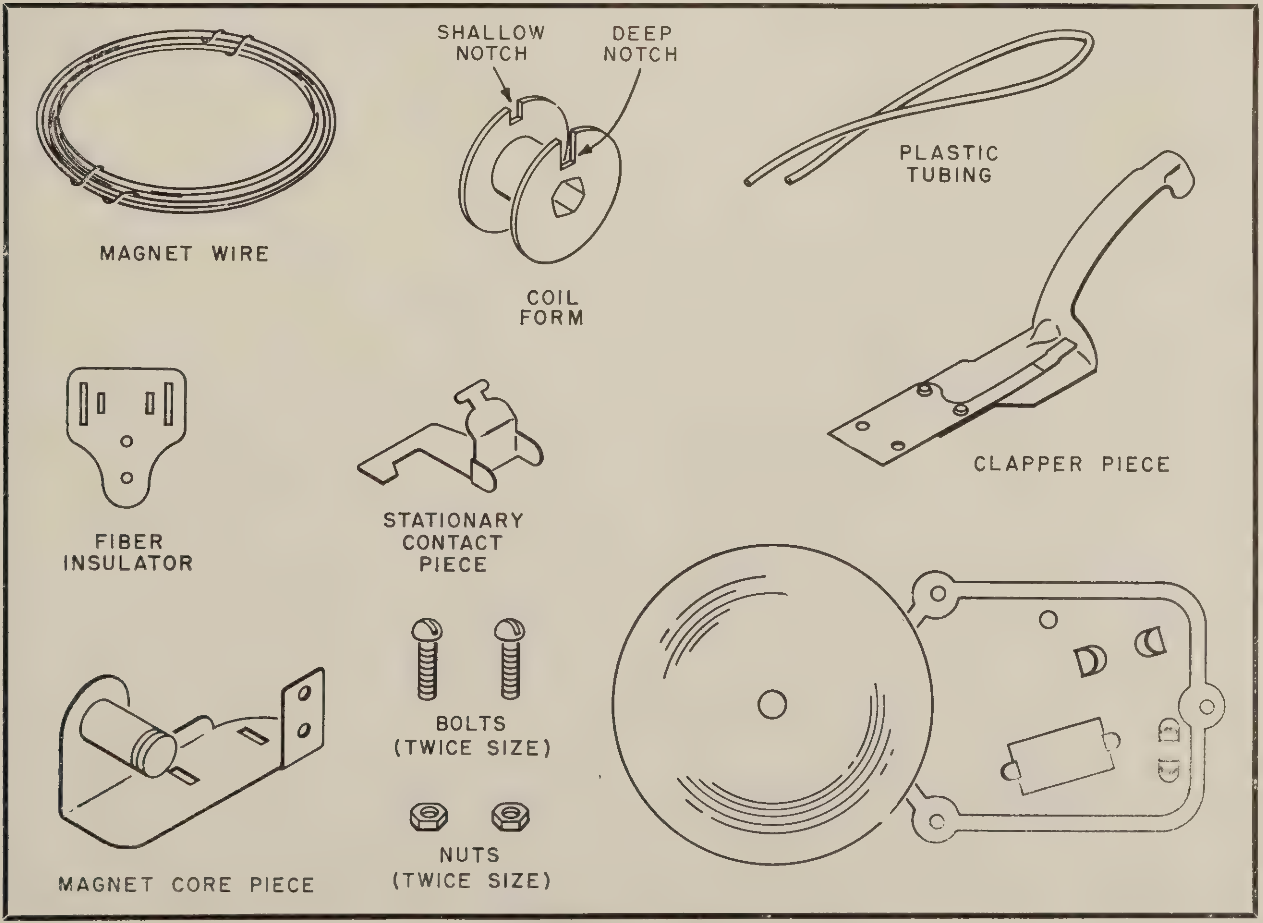


FIG. NO. 44

Open the plastic bag holding the bell kit and empty its contents into an empty space in one of the blister trays. Be careful not to lose anything from the bag. Match the parts in the bell kit to the parts display in *Fig. No. 44*.

Fig. No. 45 show how a bell works. When the circuit is closed, the electromagnet attracts the clapper. As the clapper is pulled toward the magnet, the electrical connection between the clapper contact and the fixed contact is broken, turning off the magnet. The clapper moves on to strike the bell because of its momentum. Then the spring moves it back — and once again the circuit is closed and the electromagnet turned on.

There are eight main steps to assembling your bell.

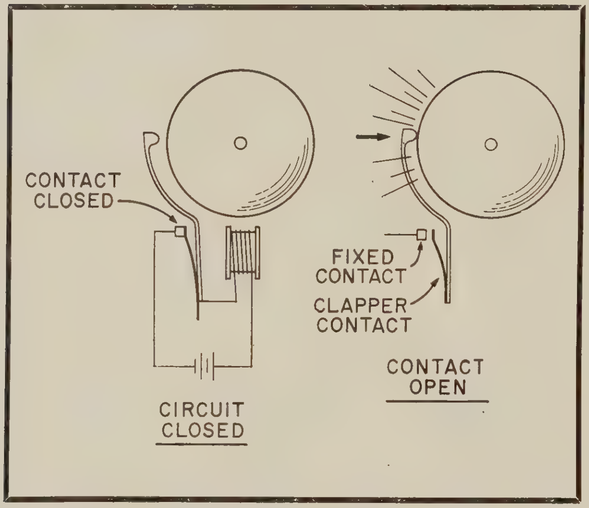


FIG. NO. 45

Step 1. Winding the Magnet Coil. Cut the plastic tubing into a 3½-inch and a 2½-inch piece. Cut a 5-inch length from the end of the coil of magnet wire. Use your screwdriver to scrape the insulation from about ¾-inch of wire at each end of both pieces of wire. You can tell when you have the insulation off because the bare wire is lighter in color. Slip the 2½-inch piece of tubing over the short wire. Save for later use.

Notice the two notches on the coil form, one deep and the other shallow. Pass one end of the coil of magnet wire through the deep notch, leaving about 6 inches of the wire at the end free. Hold the wire in the notch with a finger and wind the rest of the wire into a tight coil, as in *Fig. No. 46*. Be careful not to kink or bend the wire sharply to avoid damaging the insulation.

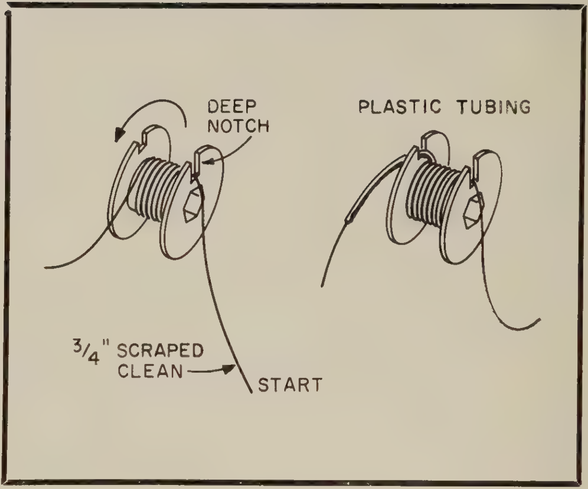


FIG. NO. 46

Stop 6 inches from the end of the wire. Slip the other piece of plastic tubing over this end of the wire and pull the wire with the tubing into the shallow notch so that the tubing is pinched in the notch. *(See Fig. No. 46)*. You may want to wrap a small piece of cellophane tape over the coil to hold the wire and tubing in place.

Step 2. Finishing the Electromagnet. Press the coil over the magnet core, as in *Fig. No. 47*. Be careful to turn the notches in the coil form as in the illustration.

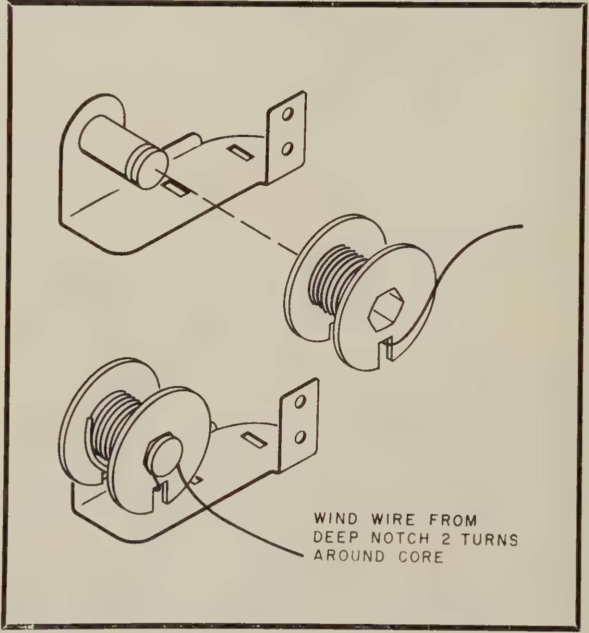


FIG. NO. 47

Wind the bare end of wire from the deep notch clockwise twice around the magnet core. *(See Fig. No. 47.)*

Step 3. Attaching the Clapper to the Magnet Assembly. In this step work with your hands over a box to catch anything you may drop. Find the two long thin bolts and the two small nuts from the blister tray with all the spare parts. Use these bolts to attach the clapper to the magnet assembly, as in *Fig. No. 48.* Use your screwdriver to fasten the bolts tightly.

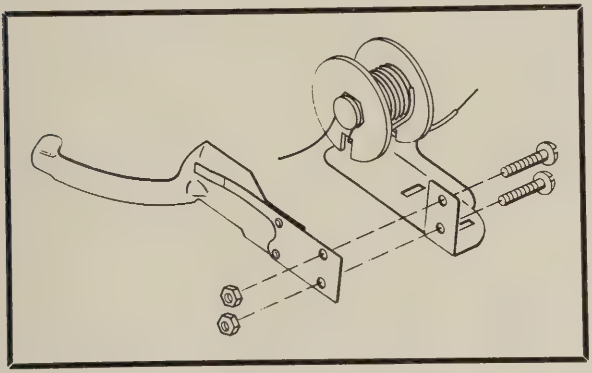


FIG. NO. 48

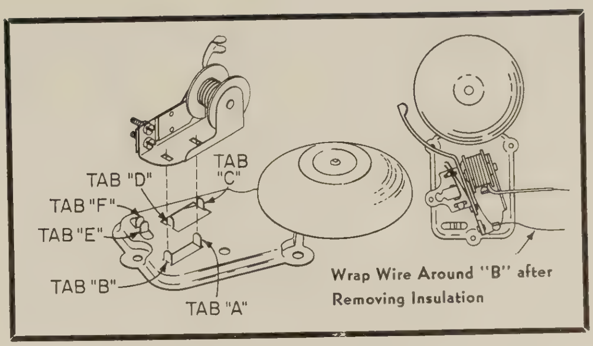


FIG. NO. 49

Step 4. Mounting and Wiring the Magnet-Clapper Assembly. Attach the magnet-clapper assembly to the base unit, fitting it over the two metal tabs as in *Fig. No. 49.* Use your screwdriver to bend Tab A.

Take the end of the coil wire from the deep notch. Stretch it out to find where it will make contact with Tab B. Use your screwdriver to scrape the insulation from the wire a half inch on either side of the contact point. Wrap the wire around Tab B one and a half times, as in the illustration. Bend Tab B with your screwdriver in the direction shown in *Fig. No. 49.* The end of the wire projecting from the tab is for use in Experiment 23.

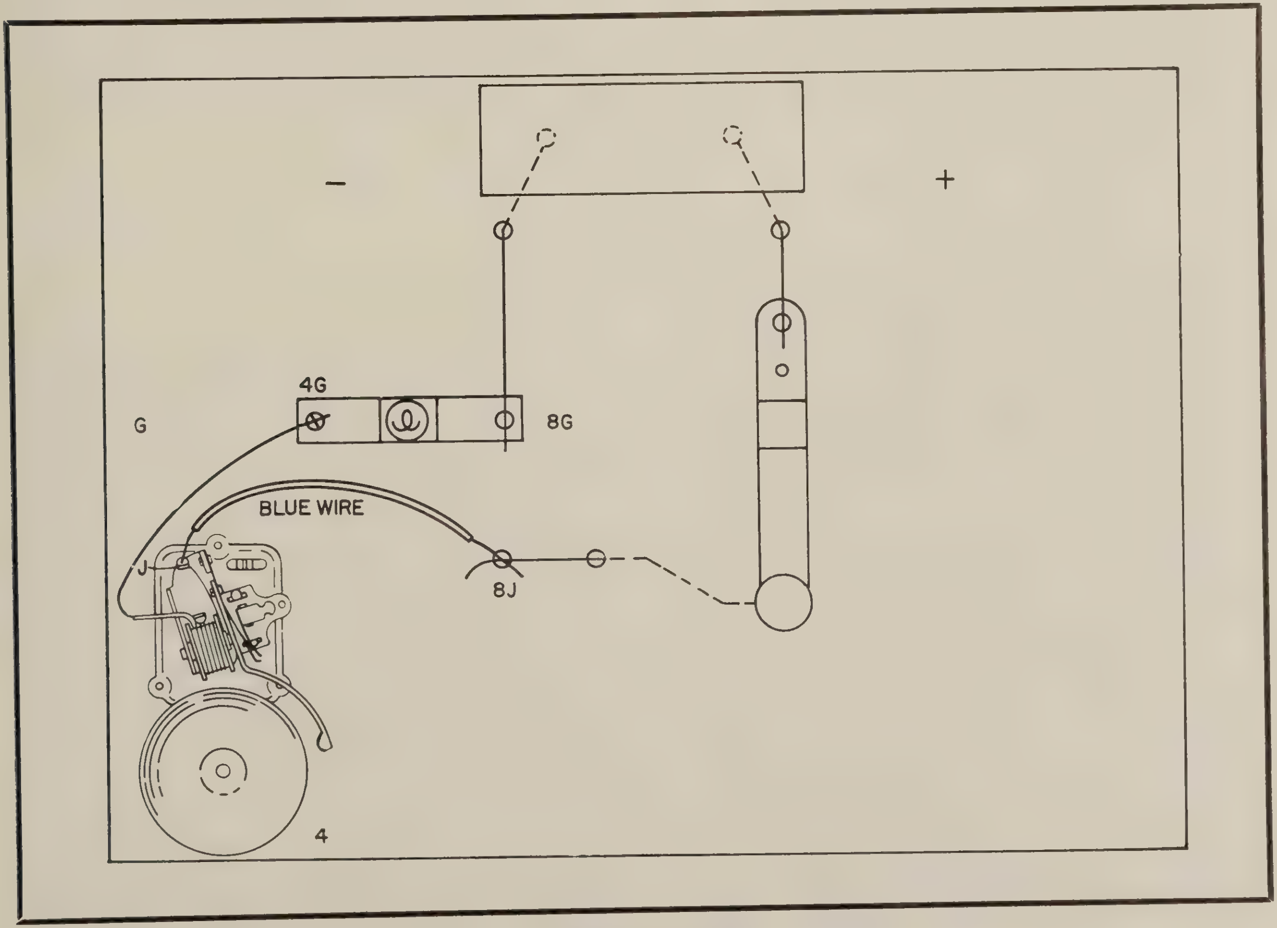


FIG. NO. 50

Step 5. Check Your Work. Notice that the electric circuit goes from the magnet coil through the magnet core piece, and from there it goes through the clapper contact plate.

Set up the test circuit shown in *Fig. No. 50.* Touch the blue test lead from connector [8-J] to the bare wire around Tab B. Press the key. Since the magnet coil has low resistance, the bulb should burn brightly. If it does not work, touch the free end of the blue test probe to connector [4-G], to make sure the circuit is working. Repeat previous step. If the bulb still will not light, check to make sure that you have scraped the wire clean at all end and contact points.

Step 6. Mounting the Stationary Contact. Attach the stationary contact piece to the fiber insulator as shown in *Fig. No. 51.* Remove the two rivets from the fiber insulator. You won't need them.

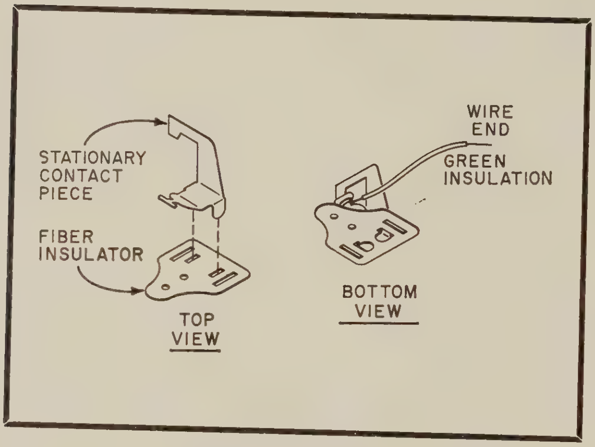


FIG. NO. 51

Take the 5-inch piece of wire that you saved. Wind one end several times around the terminal post of the contact arm — tightly. *(See Fig. No. 51.*

Mount the contact arm assembly on the base unit over Tabs C and D, as in *Fig. No. 52.* Bend the tabs as shown. Try to get the tabs bent just enough so that the fiber insulator is held firmly, yet can be moved in and out with your fingers.

Step 7. Adjusting the Stationary Contact. Set up the circuit as shown in *Fig. No. 53.* Move the contact arm in or out until you find a position in which the bell rings loudly when you close the circuit by pressing the key. Notice that if the contact arm is too far from the clapper, you will get only a buzz — because the circuit is broken too soon, before the clapper has enough momentum to strike the bell. And if you have the contact arm too close, you will get no ring or buzz at all, because the circuit won't be interrupted. When you find the best position for the contact arm, disconnect the bell from the circuit and tighten Tabs C and D.

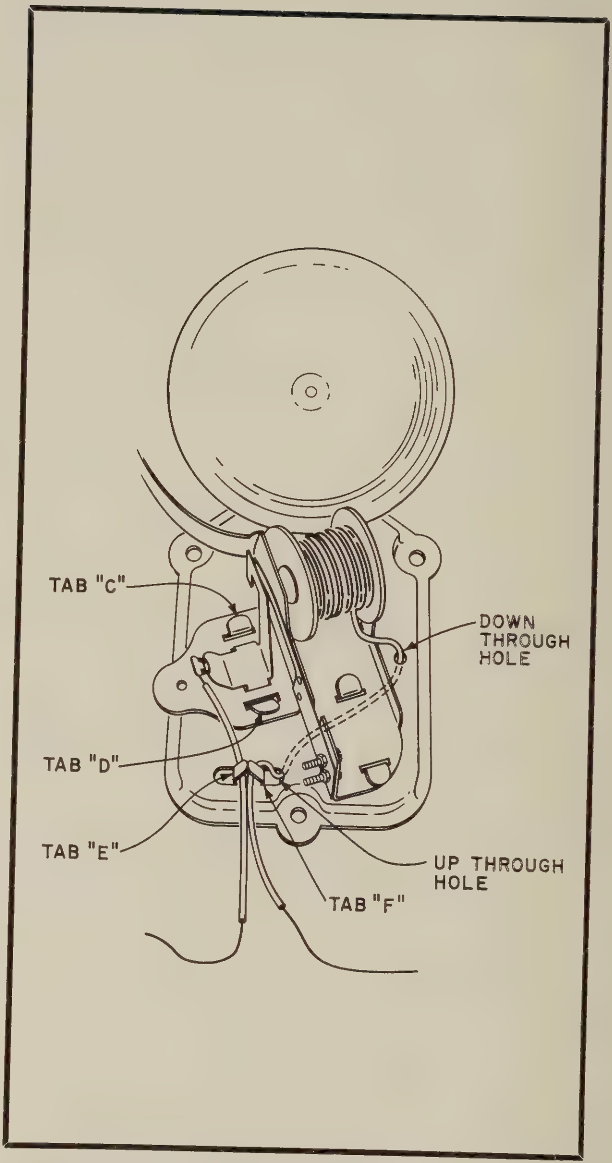


FIG. NO. 52

Step 8. Finishing Your Bell. Thread the plastic-covered end of wire from the magnet coil down through one hole in the base unit and up through the second hole, as shown in *Fig. No. 52.* Bring this and the second plastic-covered wire out between Tabs E and F. Squeeze the two tabs together to hold the wires firmly. Connect the bell again as in *Fig. No. 53.*

Your bell is finished.

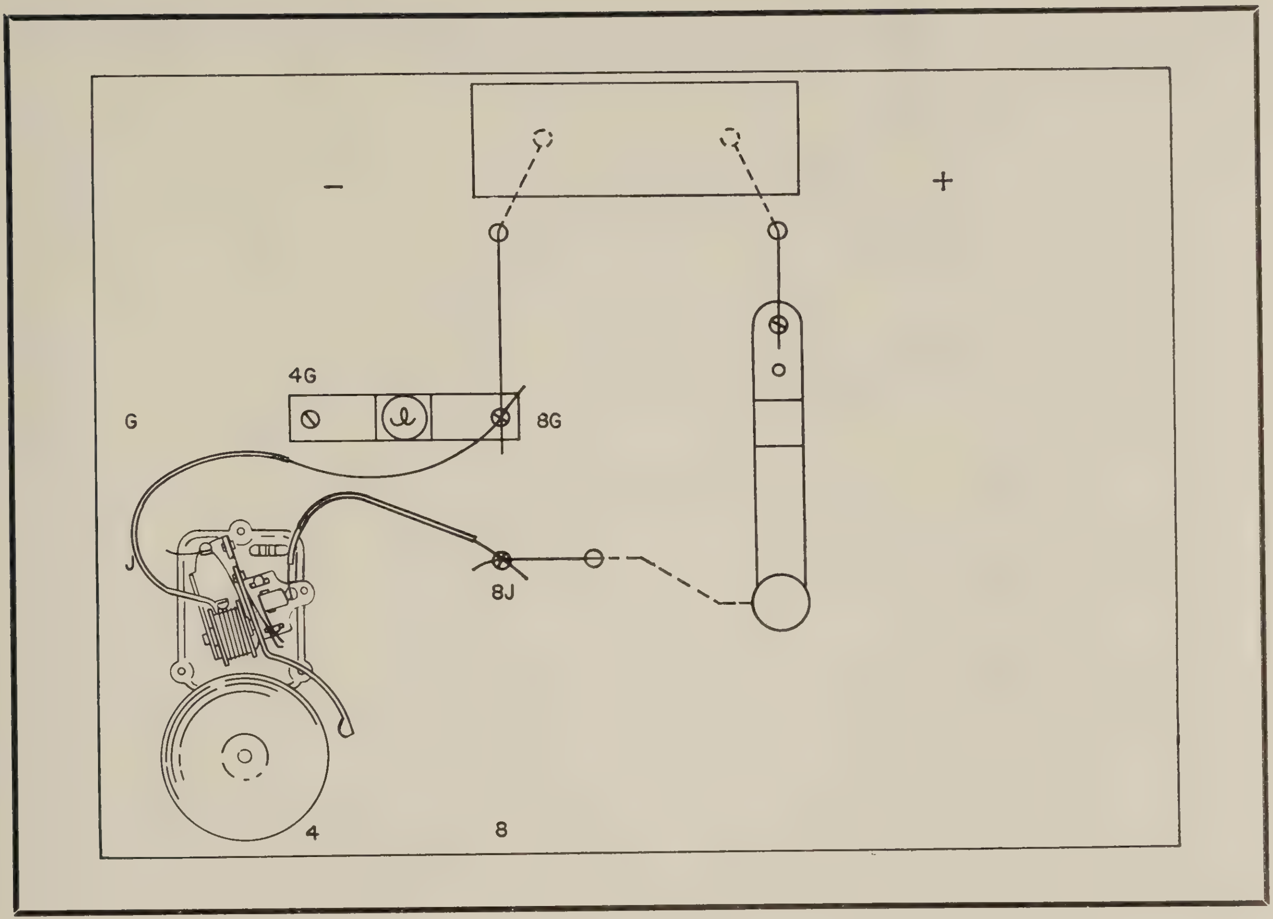


FIG. NO. 53

Experiment 23.

A TELEGRAPH CODE PRACTICE SET

Construct the circuit shown in *Fig. No. 54.* Remove the wire with the green plastic sleeve from [8-J]. Insert the wire from Tab B into [8-J]. What will happen if you press the key?

Try it and see.

In Experiment 7 you learned a little about how a message in Morse code is transmitted in "dots" and "dashes". A telegraph operator doesn't want a bell or buzzer to sound for his dots and dashes. A bell would make too much noise, and both a bell and a buzzer would be too slow. He can understand messages more rapidly if he hears a *different kind of sound* for a dot and dash.

Put one or two layers of cellophane tape over the part of the bell the clapper strikes. This will dampen the sound of the bell. Now the main sound you will hear when you press the key wil be a click from the clapper piece striking the magnet core.

An expert telegraph operator doesn't think of the words "dot" and "dash," but of the sounds "dit" and "dah." Listen carefully while you press down on the key and let go of it immediately. Can you think of this as sounding like "dit"? Now listen while you press the key down and hold it down for half a second. Can you think of this as sounding like "dah"?

The International Morse Code is given on Page 38.

If you wish to learn Morse Code, first memorize the code. Then practice with a friend. Take turns, with one of you sending while the other receives.

First practice with letters, then with single words. Don't try whole sentences until you are thoroughly familiar with the code.

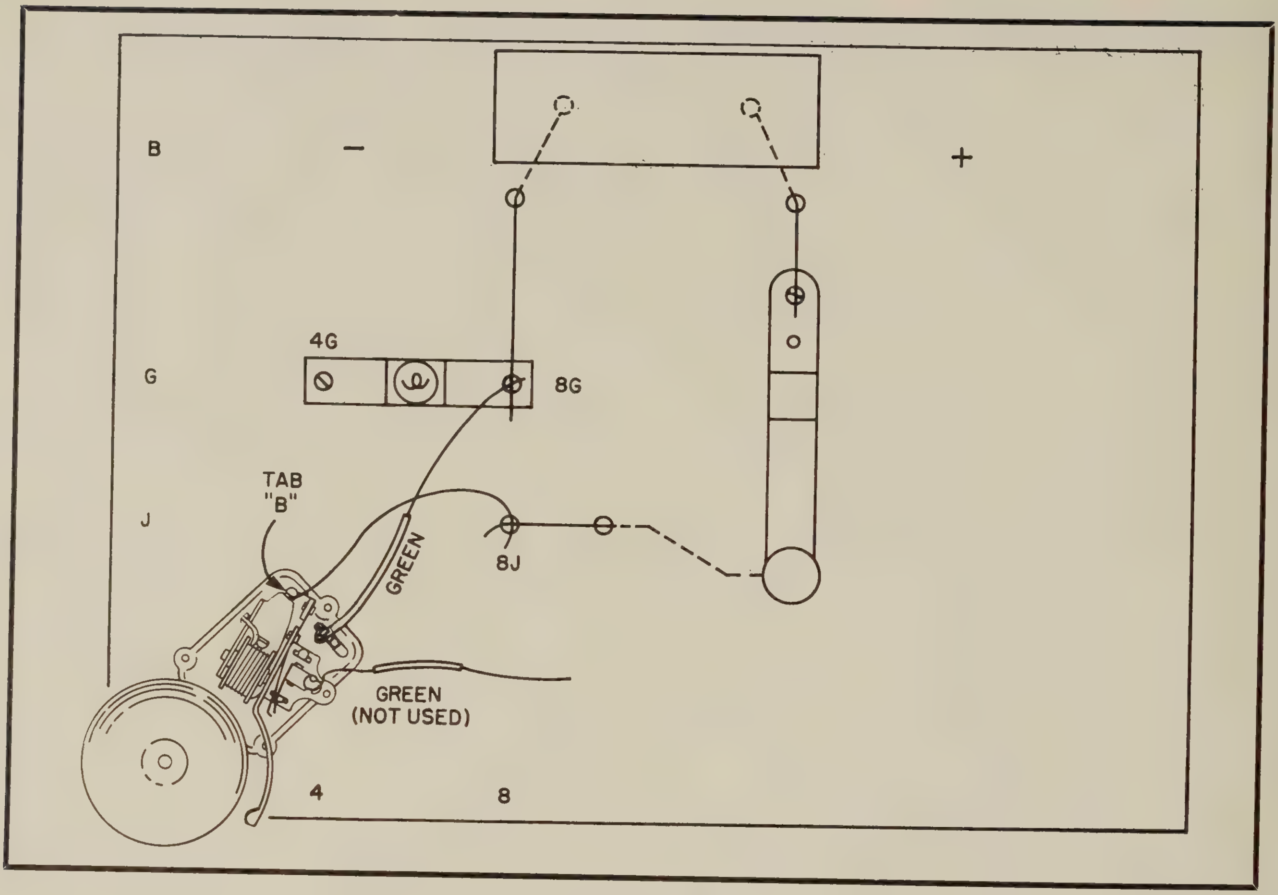


FIG. NO. 54

INTERNATIONAL MORSE CODE ALPHABET

A	·— (dit dah)	**N**	—·				
B	—··· (dah dit dit dit)	**O**	———				
C	—·—·	**P**	·——·				
D	—··	**Q**	——·—	**1**	·————		
E	·	**R**	·—·	**2**	··———		
F	··—·	**S**	···	**3**	···——		
G	——·	**T**	—	**4**	····—	**Period**	·—·—·—
H	····	**U**	··—	**5**	·····	**Comma**	——··——
I	··	**V**	···—	**6**	—····	**Question mark**	··——··
J	·———	**W**	·——	**7**	——···	**Error**	········
K	—·—	**X**	—··—	**8**	———··	**Wait**	·—···
L	·—··	**Y**	—·——	**9**	————·	**Go ahead**	—·—
M	——	**Z**	——··	**10**	—————	**End of message**	·—·—·

And now see if you can read the following message:

·—— · / ···· ·— ···— · / ·——— ··— ··· — /
·—·· ·— —· —·· · —·· / ——— —· /
—— ·— ·—· ··· / ·—·—·— / ·— ·—·· ·—·· /
·· ··· / ·—— · ·—·· ·—·· / ·—·—·— / ·—·—·

(Translation of message is on Page 50.)

Experiment 24. MAKING AN ELECTRIC MOTOR

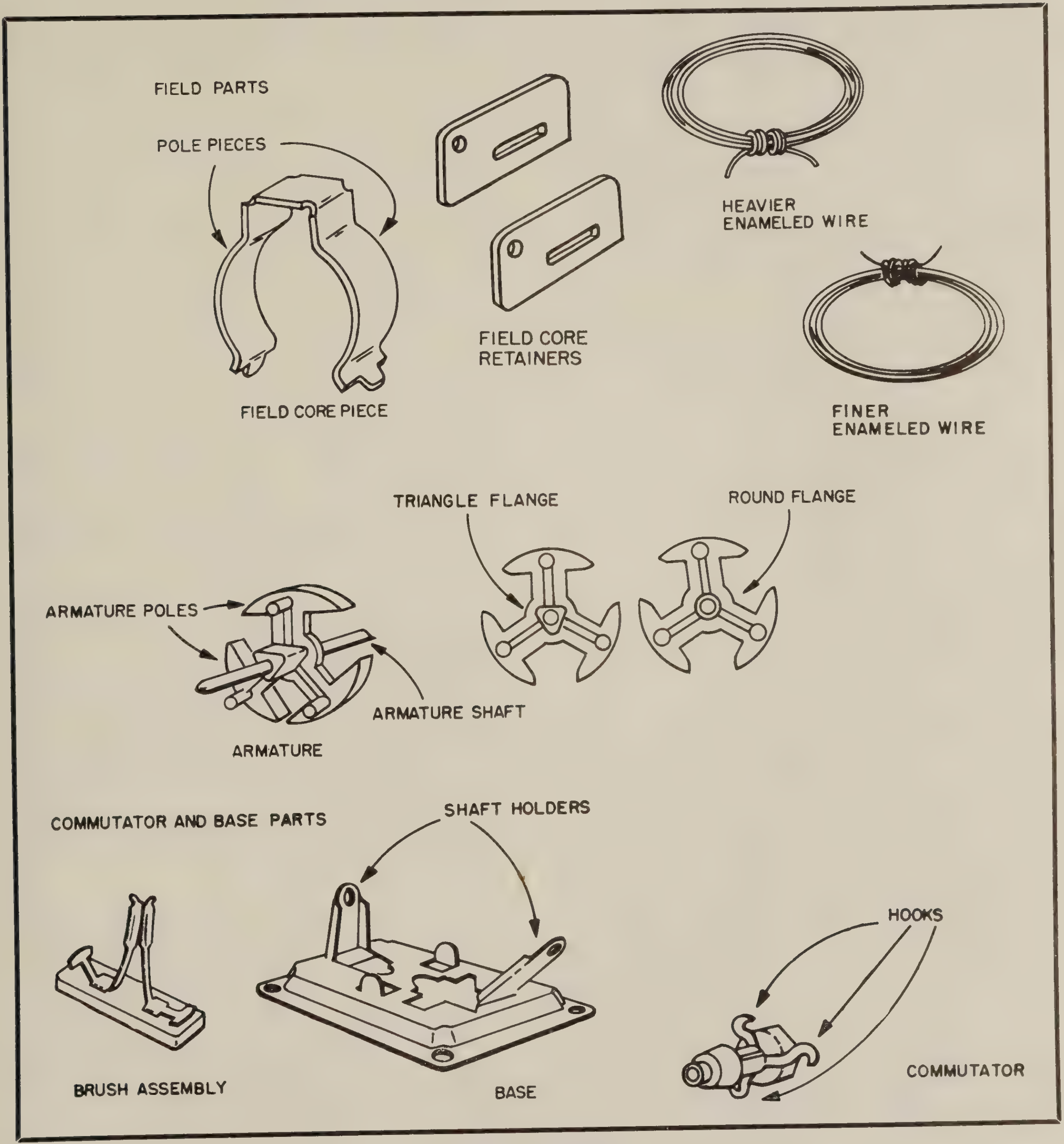


FIG. NO. 55

UNPACKING THE MOTOR KIT

Obtain 3 small containers, such as jar tops or cups. Open the plastic bag holding your motor kit, and take out the parts one at a time. Match each part with the parts display in *Fig. No. 55* and put it in one of the containers. Group your parts the way they are grouped in the parts display. BE CAREFUL! Your motor kit contains 11 separate parts, and some of these are quite small. Work with your hands over a box as much as possible.

HOW DOES AN ELECTRIC MOTOR WORK?

Hold the armature and field core pieces together, and notice that there is space for the armature to turn inside the field core piece without hitting it.

In building your motor you will wind coils on the armature and on the field core pieces. This will make them electromagnets when current goes through the coils. Then magnetic attraction and repulsion between the armature and field will cause the armature to rotate, as shown in *Fig. No. 56.*

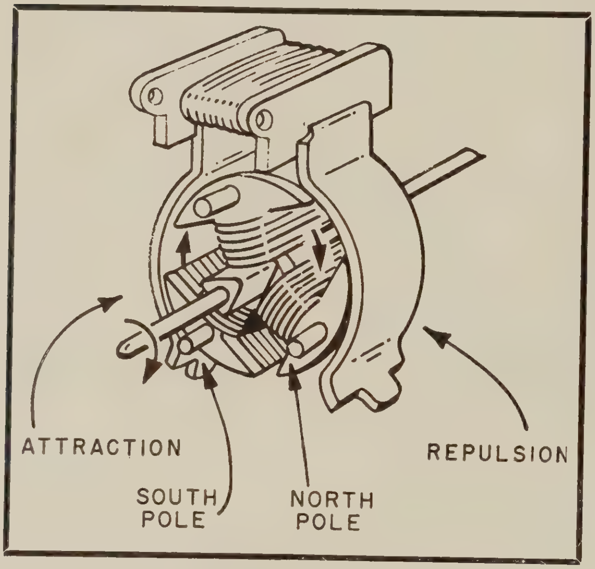


FIG. NO. 56

Your motor is a direct current motor. If you simply fed current into the armature and field coils, the armature would turn until the magnetic forces balanced out, and then stop. This is prevented by a device on the armature shaft, the *commutator*. At the instant necessary to keep the armature turning, the commutator reverses the flow of current in the armature winding and changes the magnetic poles.

Now, let's build the motor.

ASSEMBLING THE MOTOR

Step 1. Begin with the field magnet assembly as shown in *Fig. No. 57.*

Step 2. Assemble fibre coil retainers to field magnet yoke. Both fibre coil retainers must face to each other with small holes positioned as in *Fig. 57.*

Step 3. Wrap four layers of insulating tape (cellophane tape will do nicely) around the field magnet yoke assembly as shown in *Fig. 58.* Cut tape to proper width.

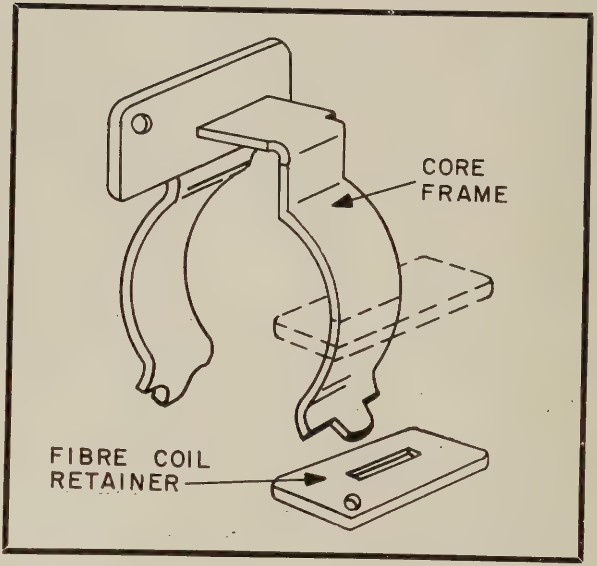


FIG. NO. 57

Step 4. Note that you have two sizes of enameled wire supplied and in this step we use the heavier size. Approximately 4 inches of the heavier wire is threaded through the hole (A) in the fibre coil retainer and the balance of the wire is carefully wound around the field magnet yoke assembly, allowing approximately 4 inches of wire, and thread this end through the other fibre coil retainer hole (B) as shown in *Fig. 59.*

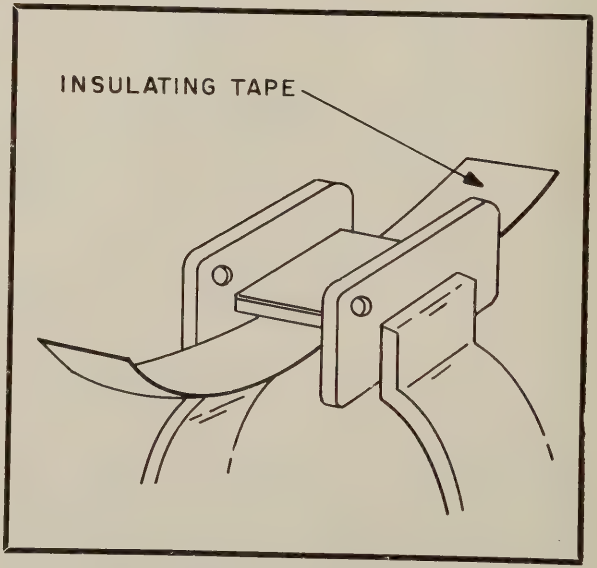


FIG. NO. 58

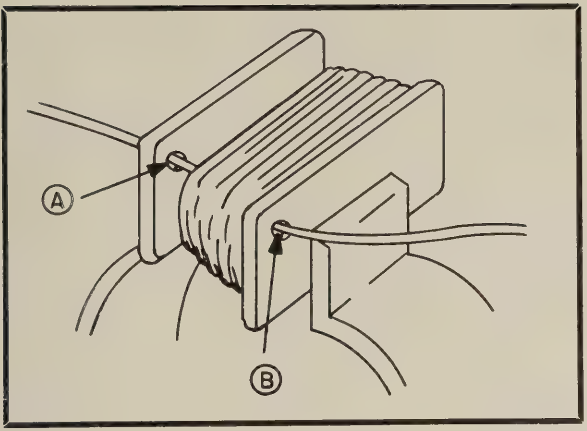


FIG. NO. 59

Step 5. Both ends of the wire are now scraped clean for good electrical connections.

Step 6. Examine the armature and notice that one end of the shaft is shorter than the other. Examine also the two plastic armature insulators and notice that one has a round flange and the other a triangular flange. The triangular part is to fit against the commutator. This armature insulator should go on the short end of the shaft. Press the two armature insulators on the shaft, right up against the armature core piece. Make sure that the insulators are turned so that their edges fit over the sides of the core piece like the lid on a box. *(See Fig. No. 60.)*

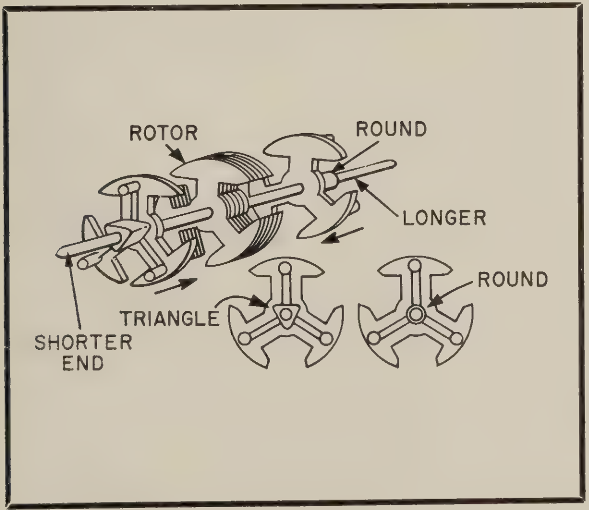


FIG. NO. 60

Step 7. Examine the two ends of your commutator and notice the triangular hole in one end. This is to fit over the triangular flange on the armature insulator. Press the commutator down over that end of the armature shaft until the two triangular parts lock together. Try not to bend the three metal hooks on the commutator. Make sure the commutator is locked firmly into place with the hooks midway between the armature segments. *(See Fig. No. 61.)* This is necessary to make the reversal of current flow occur exactly when it should.

Step 8. Refer to *Fig. 62* and study the direction of rotation of the windings for the armature assembly before proceeding with this step.

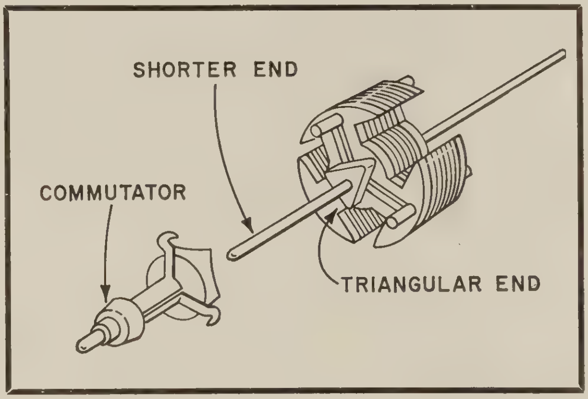


FIG. NO. 61

Step 9. Unroll the hank of small diameter enameled wire carefully to prevent any kinks.

Step 10. As illustrated, hold a part of lamination cores with your fingers tightly, setting the shaft upon your finger. Leaving about 2 inches, start winding the wire clockwise and turn 30 times on one lamination core.

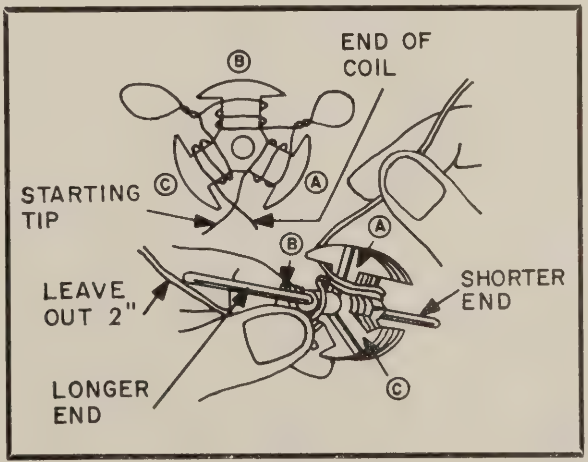


FIG. NO. 62

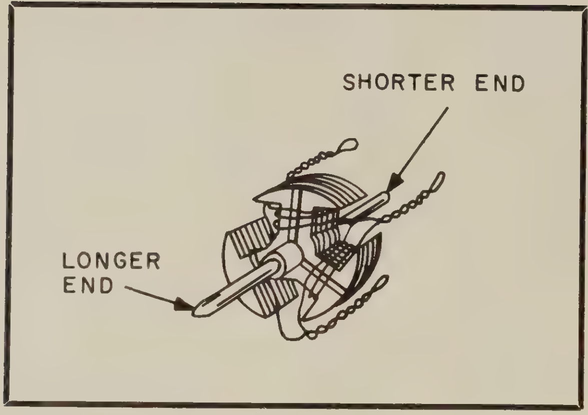


FIG. NO. 63

Step 11. After 30 turns of winding on one core, extend the wire about 2 inches, twist it as in *Fig. No. 62,* and start the same winding on another core. When you finish all 3 cores cut the wire leaving an end of about 2 inches. Both first and last ends of 2 inch wire are put together with a twist.

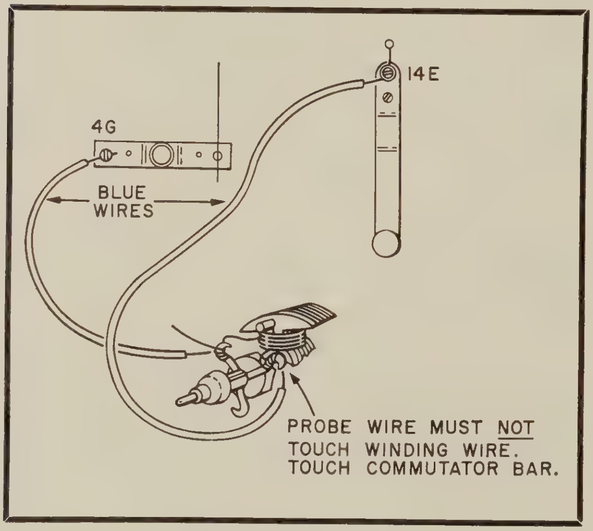

14E
4G
BLUE WIRES
PROBE WIRE MUST NOT TOUCH WINDING WIRE. TOUCH COMMUTATOR BAR.

FIG. NO. 64A

Step 12. The wire cut off in *Step 11* should be kept carefully for other wiring.

Step 13. The 2-inch excess wires are now twisted tightly, scraped clean of insulation, and then bent over so they are now facing in the direction of the short shaft. *(See Fig. No. 63).* Then wind one set of twisted wires around one of the three hooked tabs. Do likewise with the remaining sets of twisted wires on the remaining tabs.

Step 14. Now test your connection by touching the test probes to the wired commutator bars as shown in *Fig. No. 64A.* The bulb should burn brightly. If it does not, find which connection is bad. Unwind the wire from that hook, give it a better scraping, and wind it back on the hook more tightly. Test the insulation of the wire by touching one probe to a wired commutator bar and the other to the armature shaft, as shown in *Fig. No. 64B.*

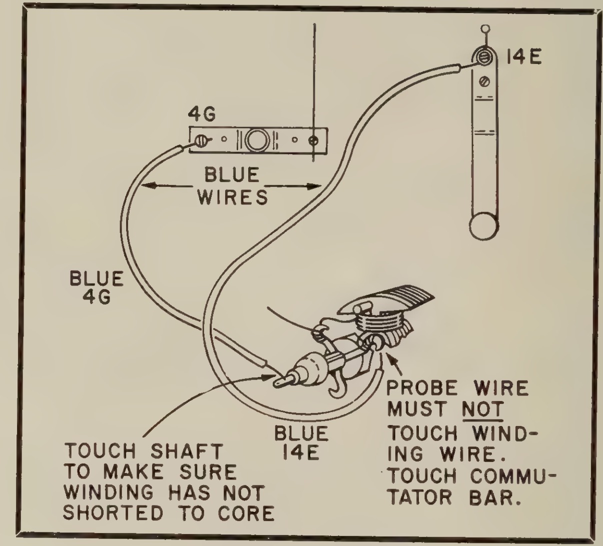

14E
4G
BLUE WIRES
BLUE 4G
PROBE WIRE MUST NOT TOUCH WINDING WIRE. TOUCH COMMUTATOR BAR.
BLUE 14E
TOUCH SHAFT TO MAKE SURE WINDING HAS NOT SHORTED TO CORE

FIG. NO. 64B

Step 15. If the bulb lights, it means the insulation is broken somewhere and bare wire is touching the metal of the armature core piece. If so, try unwinding the coil and winding it over again.

Step 16. Prepare to mount field magnet on mounting plate. *(See Fig. 65.)*

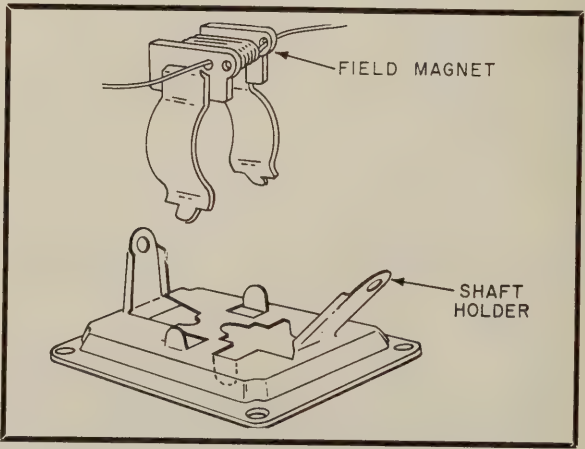


FIG. NO. 65

Step 17. Mount the field magnet assembly on the field insulating plate. It will be necessary to squeeze the pole pieces toward each other a little to do this. *(See Fig. No. 65.)*

Step 18. Bend the shaft holder at the brush end with your fingers so that you can mount the armature. Press the other bushing on the shaft to hold the shaft in place. *(See Fig. No. 66.)* Mount the armature and bend the shaft holder back up.

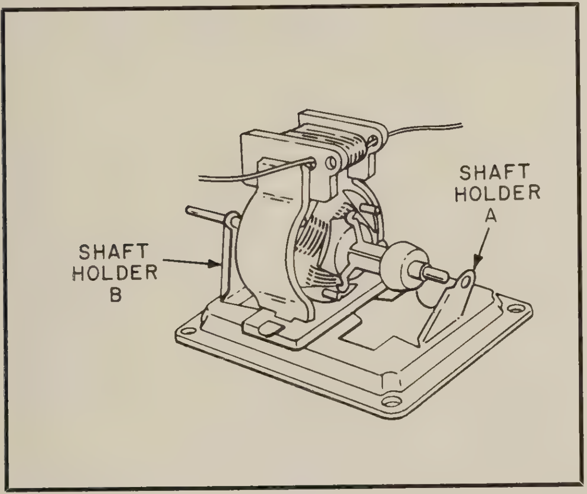


FIG. NO. 66

Step 19. Take the extra wire you saved when winding the armature. Cut it into two equal parts. Clean the insulation from ¾ inch at each end. Wrap the wires tightly around the brush tabs, as in *Fig. No. 67.*

Step 20. Mount the brush assembly from underneath the base. Make sure that both wires are pulled through the rectangular opening in the base. Gently spread the brushes so that one goes on either side of the commutator. Fasten the brush assembly in place by bending the tabs outward.

Step 21. Test to make sure you have no short circuit. With your light bulb in series as in *Step 14,* see if any current flows from either the field coil or the brushes to the metal of the base.

Step 22. Put a tiny drop of light oil on each bearing and on the commutator. You've built your own motor.

TESTING AND OPERATING YOUR MOTOR

A new motor often needs adjustment in order to operate satisfactorily. Here is how to go about checking and adjusting your motor.

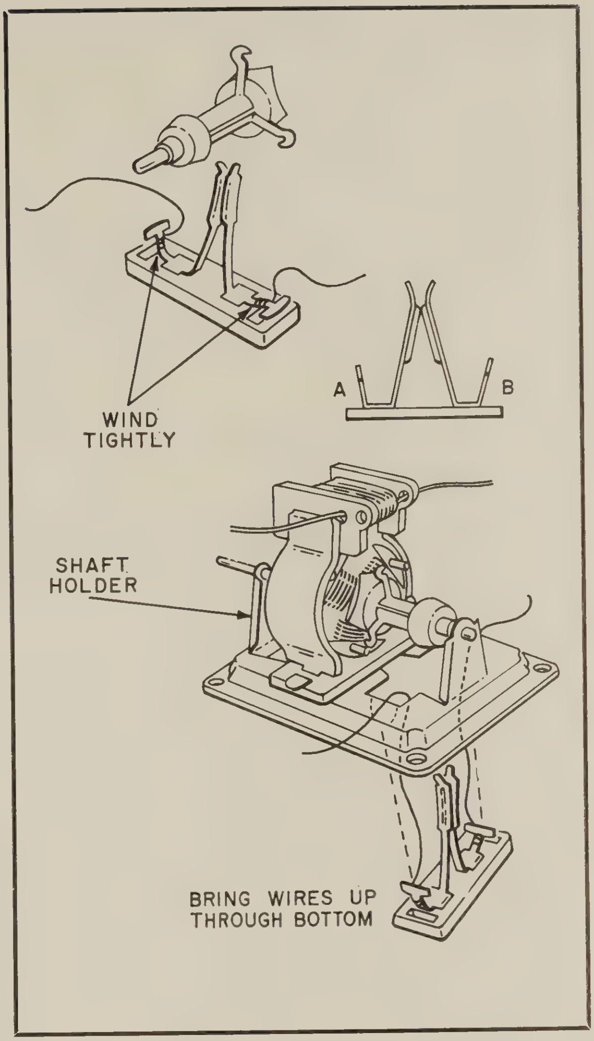


FIG. NO. 67

The brushes should be near the middle of the commutator. If not, bend the shaft holders a little or move the bushing at the end slightly. Spin the armature with your fingers. It should turn easily and keep turning for at least 2 seconds after you let go. If not, the two bushings may be too far apart and may be clamping the shaft holders too tightly.

Connect your motor as shown in *Fig. No. 68.* Press the code key. If the motor does not start immediately, spin the shaft with your fingers. You may have to start the motor with your fingers the first two or three times. After that, it should start by itself.

If the motor continues to be balky in starting, try a new set of batteries or adjustment of brush pressure.

If the motor does not run at all, check connections in the circuit and the motor itself, making sure that all connections are scraped clean. Put a light bulb in series with the motor.

Watch the bulb as you turn the armature by hand. If the light goes on and off, the brushes are not making good contact with the commutator. Bend them toward each other slightly to increase the contact pressure.

If the bulb does not light at all, look for a bad connection.

Don't run your motor too long at a time or you will wear out the batteries. Rest the batteries a minute or so between runs.

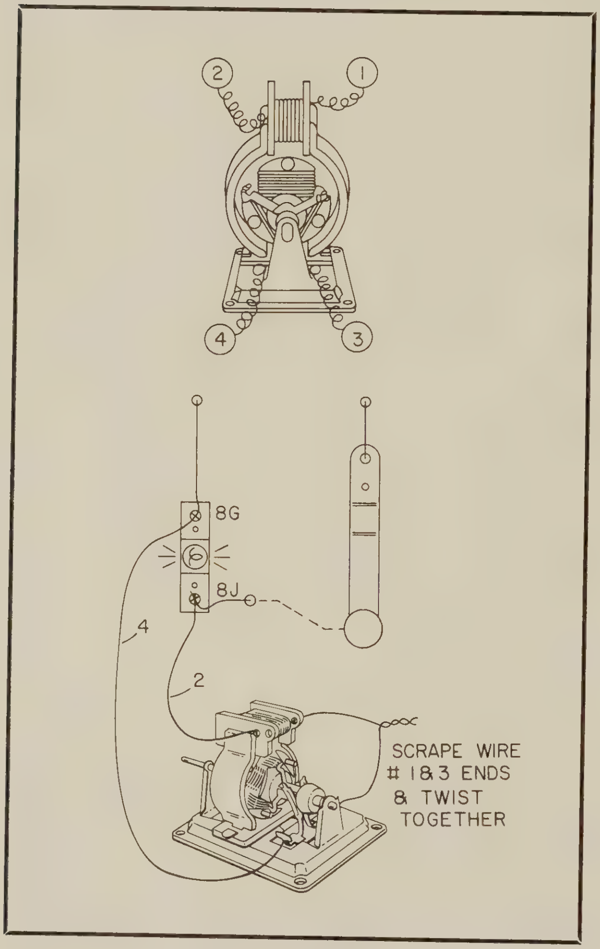


FIG. NO. 68

Experiment 25.

EXPERIMENTING WITH YOUR MOTOR

By this time, you are becoming an experienced experimenter. In this last experiment, therefore, we are going to tell you less and put you more on your own. Let's see how well you do!

Clockwise or counter-clockwise? First, let's see why the motor turns in the direction it does. Study *Fig. No. 69*. The field and armature poles will be north poles and south poles when current is flowing as shown.

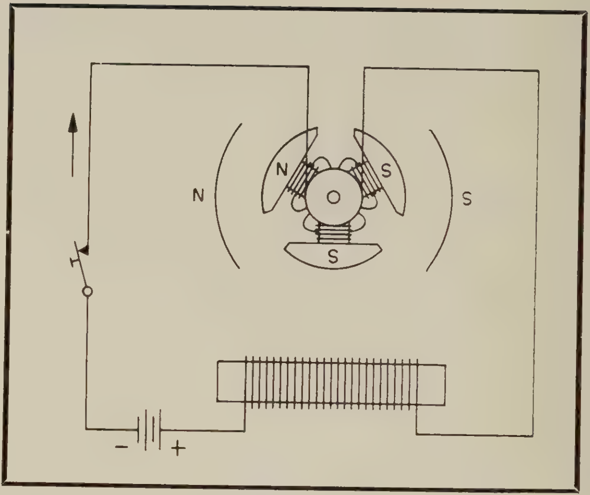


FIG. NO. 69

Notice that you can use your compass to check the polarity of the field magnet poles while you run the motor for a few seconds.

Now study the four circuit diagrams in *Fig. No. 70*. On *Fig. No. 70A*, draw an arrow to show which way the motor turns. Try to predict which way it will turn when you reverse the field current. *(Fig. No. 70B)*, reverse the armature current *(Fig. No. 70C)*, and reverse the current through the whole motor *(Fig. No. 70D)*. Draw arrows to show what you predict.

Now connect the motor in all four ways shown in *Fig. No. 70*. Were you correct? If not, where did you go wrong?

In a motor of this kind, the direction of rotation does not change when the field and the armature current are changed together. As a result, it will run on either alternating or direct current, and is an AC-DC motor.

Generating Electricity. An electric motor can be used to generate electricity. You can generate a detectable electric current with your motor if you can turn it fast enough with your fingers.

How can an electric motor generate electricity? Here are the basic facts. As you know, a moving electric charge produces magnetism. In a somewhat similar way, *a moving magnetic field generates electricity.*

A moving magnetic field can cause electrons to move. If there is a conducting circuit arranged in the right way, a current will flow in the circuit.

Here we meet the Theory of Relativity again. What counts is the motion of the magnetic field relative to the conductor. Electricity will be generated whether you have a moving mag-

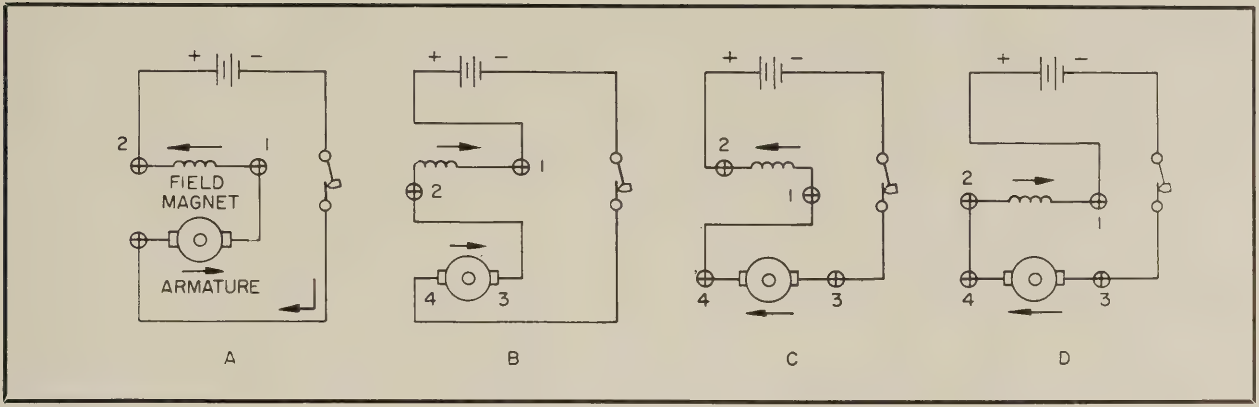


FIG. NO. 70

netic field and a stationary conductor, or a stationary magnetic field and a moving conductor. In the case of your motor in this experiment, the magnetic field will come from the field magnet, which is stationary. The armature windings will be the conductor, and they move.

Generators in power plants work on exactly the same principle of wires moving in a magnetic field.

Now let's see whether you can generate enough electricity to move the needle of your galvanometer. Set up the circuit shown in *Fig. No. 71.* The motor should be placed far from the galvanometer, so that you won't shake the galvanometer when you turn the motor by hand. Do not leave this circuit connected for too long, as it draws heavy current from the batteries.

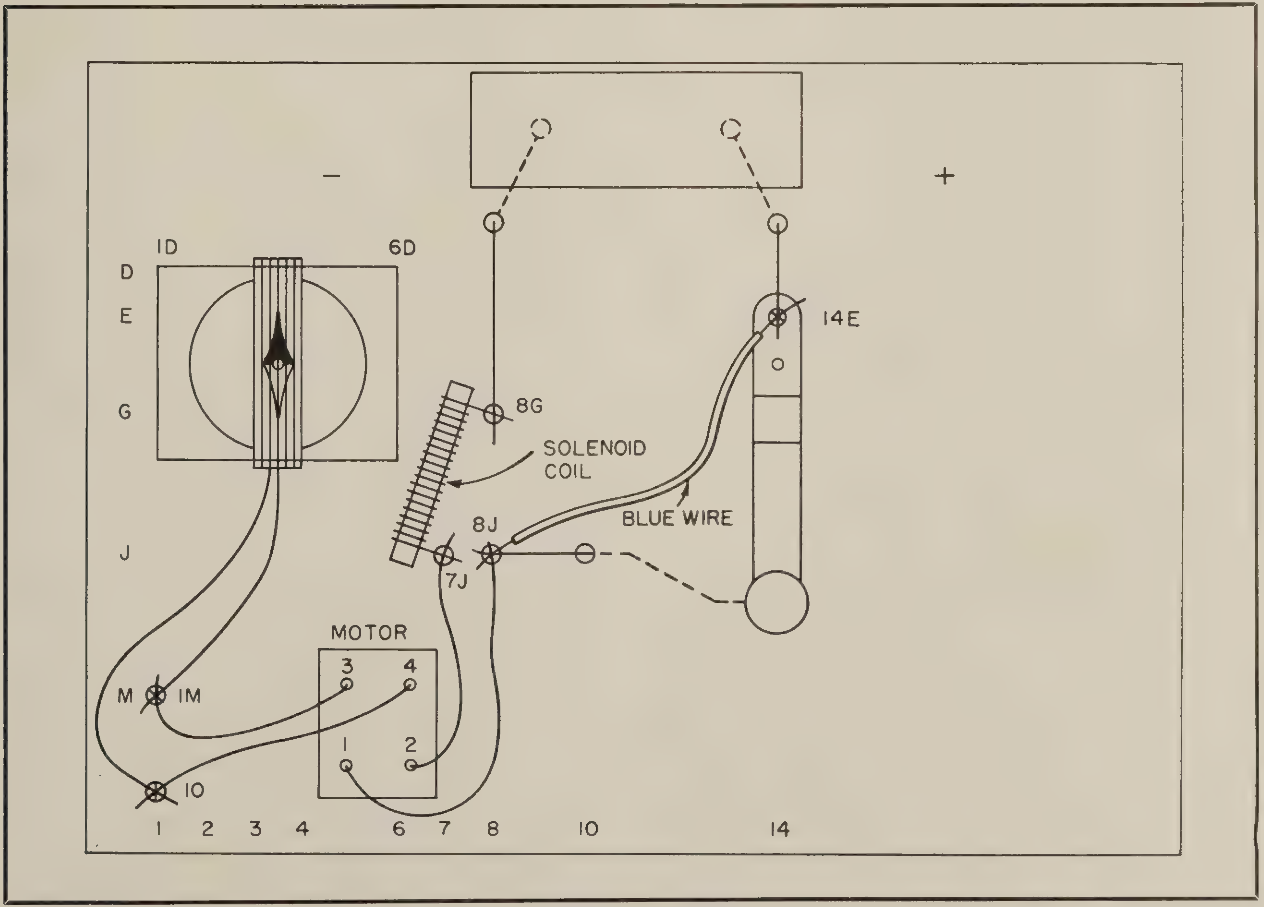


FIG. NO. 71

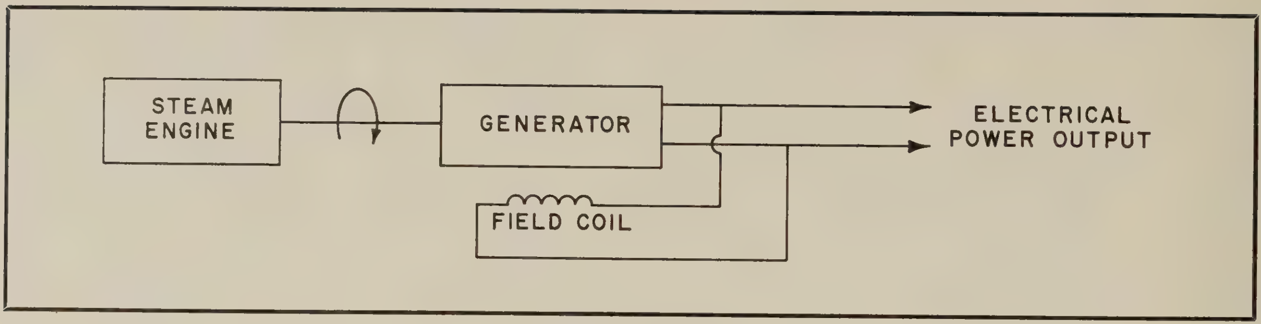


FIG. NO. 72

Spin the armature for 5 to 10 seconds. If the armature is turned fast enough, the compass needle will move a few degrees in one direction. Spin the armature in the opposite direction. The compass needle should move the opposite way. The solenoid coil is used in this experiment to limit the field current.

You are using the batteries to excite the field magnet, but if you had a little steam engine to turn the armature very fast, you would generate so much current that you could use part of it to excite the field. This is what is done in the large generators in power plants. *(See Fig. No. 72.)*

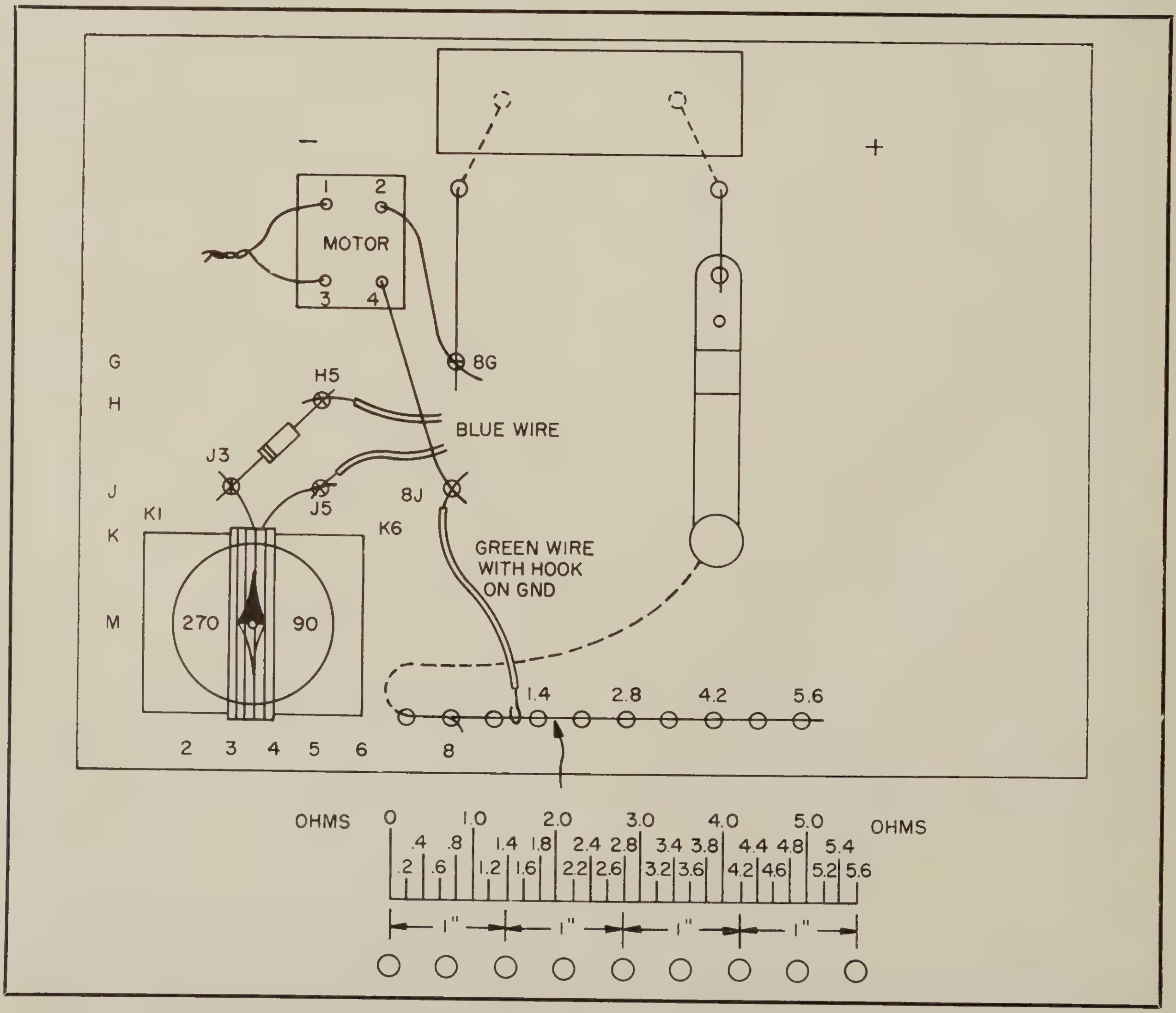


FIG. NO. 73

Electrical Engineering. Let's imagine that you are an electrical engineer. You are going to make careful measurements on your motor in order to fill in the blank spaces in this table of basic facts about your motor.

Starting Current:
(______________) amperes.

Idling Current:
(______________) amperes.

Running current at full battery voltage:
(______________) amperes.

Field resistance:
(______________) ohms.

Armature resistance:
(______________) ohms.

Total motor resistance:
(______________) ohms.

Power at full battery voltage:
(______________) watts.

As you will see, this will take some hard work. If you can do this correctly, you can be proud of yourself. You have come a long way since that first experiment in which you generated static electricity by rubbing two strips of plastic together.

To begin, read over Experiment 20 to remind yourself how you used your voltmeter.

To start with, you must calibrate your voltmeter. Set up the breadboard as in *Fig. No. 73.* Using the long blue wire, measure the voltage across one battery. We know this to be 1.5 volts. If you obtained a compass reading of 15 degrees, your voltmeter would have a sensitivity of 1.5 ÷ 15 or .1 volt per degree. If you read another voltage, and obtain a reading of 45 degrees, the voltage would be .1 × 45 = 4.5 volts. Make your sensitivity calculations and record them.

How to Connect Resistance Wire: Double the resistance wire, twist the two halves together three or four times, and attach the doubled wire to the connectors, as in *Fig. No. 73.* Now the two halves are in parallel. The resistance is therefore 1.4 ohms per inch instead of 2.8 ohms per inch. This will make your measurements more accurate.

Connect the rest of the circuit as shown in *Fig. No. 73.* Now, use one hand to press the key, and the other to hold the slider against the resistance wire. Make sure the slider hook pulls against both strands of resistance wire. Set the slider at zero resistance, and press the key. When the motor has started, move the slider to increase the resistance. Notice how the motor slows down and finally stops. Move the slider back until the motor starts again.

Attach the voltmeter between [8-0] and [8-5]. Press the key and adjust the resistance wire slider so that the motor idles, that is, runs very slowly, but doesn't quite stop. Read the compass, and use *Fig. No. 73* to read the resistance between [8-0] and the slider. Write the compass reading and the resistance here:

(______________) degrees.

(______________) ohms.

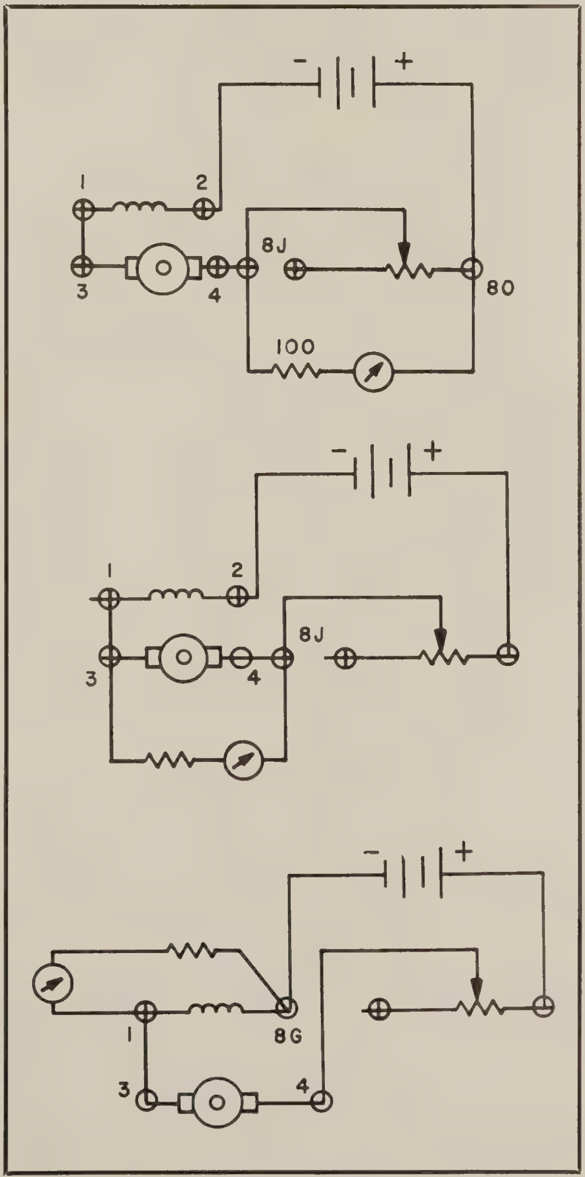


FIG. NO. 74

To find the voltage, multiply the compass reading by the sensitivity factor. Write the result here: (______________) volts.

Now you can find the current with the aid of Ohm's Law:

AMPERES = VOLTS ÷ OHMS

This is the idling current. Write it in the table on Page 47.

Now find the place on the resistance wire where the motor just starts. Calculate the starting current in the same way, from the voltage (compass reading × sensitivity) and the number of ohms of resistance (from the resistance wire). Write down the starting current in the table.

Next, measure the resistance of the field and the armature. You have already met Ohm's Law in two different forms. Now use it in this form:

OHMS = VOLTS ÷ AMPERES

Connect the voltmeter as shown in *Fig. No. 74B*. Set the resistance wire slider at the point where the motor idles. Read the compass and calculate the voltage. Write it here: (______________) volts. You already know the idling current. Use Ohm's Law to calculate the armature resistance. Enter the armature resistance in the table.

Next, connect your voltmeter across the field, as in *Fig. No. 74C* and calculate the field magnet resistance in the same way. Write it in the table.

Add the field and armature resistance to obtain the total motor resistance. Enter that in the table.

Finally, connect your voltmeter across the whole motor. Set the resistance wire at zero resistance. Read the compass and calculate the voltage. Write it here: (______________) volts. It will be less than 3.0 volts because the motor draws a very large current from the battery. The battery itself has some resistance. Therefore, when you draw much current from it, there's some voltage drop inside the battery. The more worn out the battery is, the higher its resistance is.

Use Ohm's Law to calculate the current the motor draws when you operate it on the full battery voltage. Write it in the table.

There's only one blank space in the table. "Generating and Transmitting Power" will tell you how to fill it in.

GENERATING AND TRANSMITTING POWER

Generators

You've already learned something about how a moving magnetic field generates electricity. Here's a useful rule to remember: When a conductor (such as a wire) moves so that it cuts across magnetic lines of force, a voltage is generated that tends to force electrons along the conductor. This is illustrated in *Fig. No. 75*. Notice that the conductor is moved to the left. But it would work the same way if the conductor were motionless and the magnet were moved to the right.

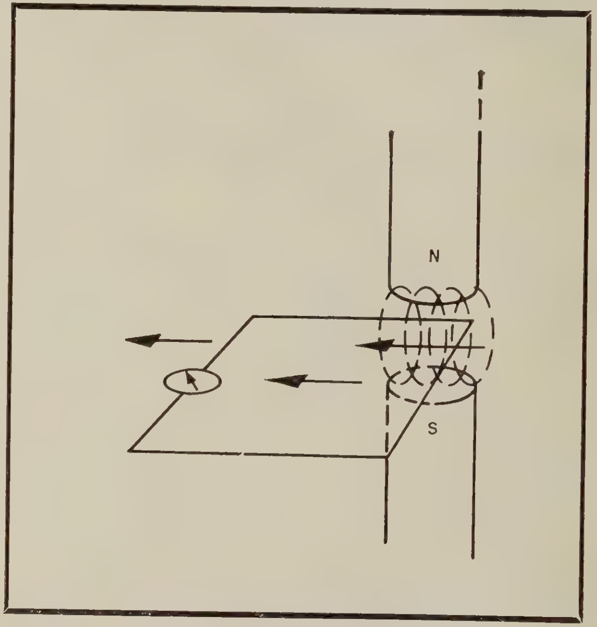


FIG. NO. 75

Now take another look at *Fig. No. 75*. The magnetic field (moving in relation to the conductor) has generated an electric current in the circuit. But, won't the electric current in that loop of wire generate a magnetic field? Yes, it will. And the field generated will have a south pole at the top and a north pole at the bottom. As a result, the magnetic attraction between unlike poles will tend to pull the coil back toward the right. This makes it harder to pull the coil to the left and generate current.

This is an example of an important scientific law called Lenz's Law. Whenever a moving magnetic field generates current, the current generates another magnetic field. And this second magnetic field is always arranged in such a way that it makes it harder to generate the current. And this is why it takes a powerful turbine to turn a large electric generator. If it were not for this Lenz Law effect, it would take no work to generate electricity.

Power and Energy

Motors and generators are described in terms of their *power*. Just what do we mean by "power"? Power is the speed or *rate* at which motors use energy, or the *rate* at which they do work.

Electric power is measured in *watts*. It is easy to calculate the number of watts. Simply multiply volts times amperes.

1 VOLT × 1 AMPERE = 1 WATT

For example, if your household electric current is 120 volts and you have a light bulb that draws ½ ampere, then it is a 60-watt bulb:

120 volts x ½ ampere = 60 watts

Now you can finish the table on Page 47. You measured the full battery voltage across the motor, in Experiment 25, and you calculated the current. Now calculate the electric power used by the motor in watts.

When the electric company bills your parents, it charges them for the total amount of electric *energy* they have used. To find the energy, you multiply the wattage by the time during which that amount of power is used. Thus, a 60-watt bulb left on for an hour consumes 60 watthours of energy. Since a *watthour* is a very small unit, we ordinarily use the *kilowatthour*, which represents the expenditure of 1000 watts of power for an hour.

Alternating Current

Why is alternating current used so much more than direct current? The main reason is that it isn't easy to change DC from one voltage to another without losing power. This is easy to do with AC.

Let's see how this works.

Suppose an electric company wants to supply 1,000,000 watts of power to a city 100 miles away. It might try to do this by supplying 100,000 amperes at 10 volts. But then it would be trying to use a small pressure to drive a huge number of electrons a very long distance. Even if it used copper wires 10 feet in diameter (and costing millions of dollars) to lower the resistance, it would still take so much power to drive the electrons through the wires that very little power would be left for the city to use.

What the electric company does instead is to transmit 10 amperes at 100,000 volts. Then it will be moving a much smaller number of electrons, and have much higher pressure to drive them along the wire. It can use comparatively thin, inexpensive wire, and still lose little power in transmitting the current. Most of the power will be left for the city to use.

The electric company generates power at a voltage low enough so that it's convenient to work with — say, 10,000 amperes at 100 volts. Then it transforms this to 10 amperes at 100,000 volts for transmitting it. At the city, the power is transformed back to a large amount of current — at 115 volts for safe use in homes and offices.

The voltage is changed by means of a device called a *transformer*. Transformers work on AC only, not on DC.

Fig. No. 76 shows how simple a transformer is. It's just an electromagnet with two coils. An alternating current in one coil induces a current in the other. The same amount of power that is put in comes out (less 2 per cent or so lost as heat). To find how much the voltage changes, count the number of turns in each coil. For example, if one coil has 100 turns and the other 200, a 10-volts in the first coil will come out of the second as 20 volts.

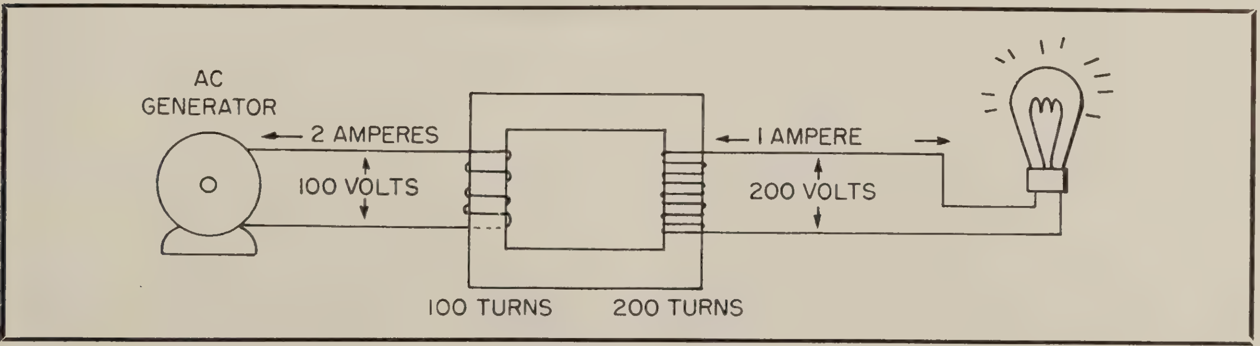


FIG. NO. 76

PART 9

SUGGESTIONS FOR FURTHER READING

If you want to learn more about electricity and magnetism, here are some interesting books.

For Younger Readers:

Morgan, Alfred
A FIRST ELECTRICAL BOOK FOR BOYS
Scribner's, New York, 1954

Yates, Raymond
THE BOYS' BOOK OF MAGNETISM
Harper, New York, 1959

For Seventh Grade and Up:

Morgan, Alfred
ADVENTURES IN ELECTROCHEMISTRY
Scribner, 1959

Dunsheath, Percy
ELECTRICITY: HOW IT WORKS
Crowell, 1960

Bitter, Francis
MAGNETS: THE EDUCATION OF A PHYSICIST
Doubleday Anchor Books, 1959

High School Level:

Physical Sciences Study Committee
PHYSICS
Heath and Company, 1960

Marcus, Abraham
BASIC ELECTRICITY
Prentice Hall, 1958

Efron, Alexander
MAGNETIC AND ELECTRICAL FUNDAMENTALS
John F. Rider Publisher, New York, 1959

Morse Code Message on Page 38: "We have just landed on Mars. All is well. End of message."

WARRANTY

General Electric Company warrants to the purchaser of this new Electronics Lab, that the resulting unit will function when properly assembled. Should any part of this Lab prove to be defective in material or workmanship within 90 days from the date of original purchase for use, such defective parts will be repaired or replaced free of charge by sending the defective part along with the service coupon to General Electric Company, Educational Science Kit Section, Product Service, 1001 Broad Street, Utica, New York. Under no circumstance does this warranty extend to parts damaged by the user. The Company has no other obligation or liability in connection with said Lab.

This warranty applies only to products purchased for use within, and retained within, the continental limits of the United States, Alaska, and Hawaii. The Company makes no warranty, expressed or implied, to purchasers located elsewhere.

See the Replacement Parts list for instructions about ordering replacement parts.

This series of manuals has been specially prepared in collaboration with General Electric engineers by the following group of writers and specialists: Leonard Engel, Executive Editor; Dr. Theodore Benjamin, Len Buckwalter, Alex Dorozynski, Barbara Land, Patricia Lauber, Dr. George R. Price, and Wallace K. Waterfall.

GENERAL ELECTRIC

PRODUCT SERVICE

SERVICE FOR ASSEMBLED EXPERIMENTS

If the finished assembled experiment does not operate according to the instructions in this manual, we recommend that you write us a letter giving us details of what you believe is defective. We will review your letter and will assist you in getting your experiments to operate properly via mail. Do not return your kit to the factory.

ORDERING ADDITIONAL REPLACEMENT PARTS

Should you desire an additional part, you may obtain it by filling in the part catalog number on the Service Coupon at the bottom of this page and mail it with your remittance to General Electric Company, P. O. Box 831, Utica, N.Y. On orders of one dollar ($1.00) or more, please enclose check or money order in the exact amount PAYABLE TO THE GENERAL ELECTRIC COMPANY. On orders for less than one dollar ($1.00), coins will be accepted.

EL 20 — SERVICE COUPON

Please send me the following parts:
Qty. Catalogue No. Description Price

Total amount enclosed: $____________

Please send me a replacement part for the following in-warranty defective part:
Catalogue No. Description

Please mail to:

Name_____________________________________

Address___________________________________

City____________________ State______________

REPLACEMENT PARTS LIST

EL-20

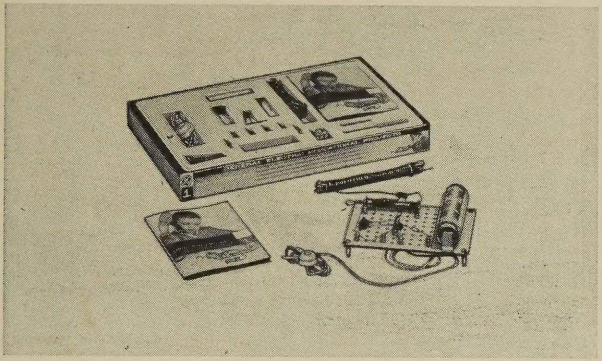
Catalog No.	Description	Unit Price
EK113	Spring Connector Assembly (5)	.25
EK116	Screwdriver	.25
EK121	Screw, Component Mtg. (7)	.25
EK122	Fastener, Speed Nut (pkg. of 5)	.25
EK147	Connector, Tool (Code Key Knob)	.25
EK157	100 ohm Resistor (½ watt) (R1)	.25
EK190	Coil Support	.25
EK191	Powdered Iron	.50
EK193	Coil Form	.25
EK194	Fastener, Speed Nut (Code Key)	.25
EK197	Lamp, #49	.25
EK198	Lamp Socket	.25
EK199	Electroscope Stem Assembly	.25
EK206	Motor	.75

Catalog No.	Description	Unit Price
EK207	Bell	.75
EK208	Pith Ball	.25
EK209	Bar Magnet	.25
EK224	Screw, Bell (pkg. 5)	.25
EK225	Hex-Nut (pkg. 5)	.25
EK252	Plastic Cover	2.00
EK253	Assembly Board	.50
EK254	Frame, Plastic (2 pieces)	.50
EK316	Battery Clip	.25
EK317	Battery Holder	.25
EK318	Contact Spring (neg. batt.)	.25
EK322	Code Key Mounting Board	.25
EK323	Code Key Shaft	.25

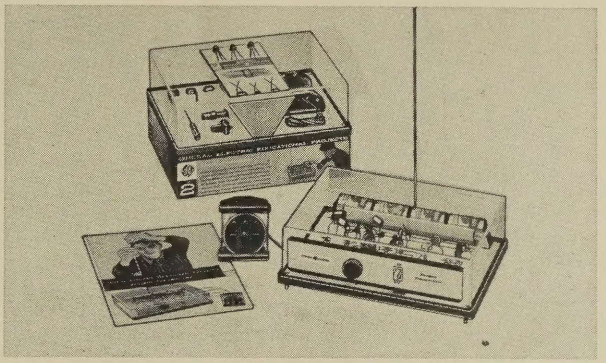
(The above prices include the standard fee for handling costs.)

OTHER KITS

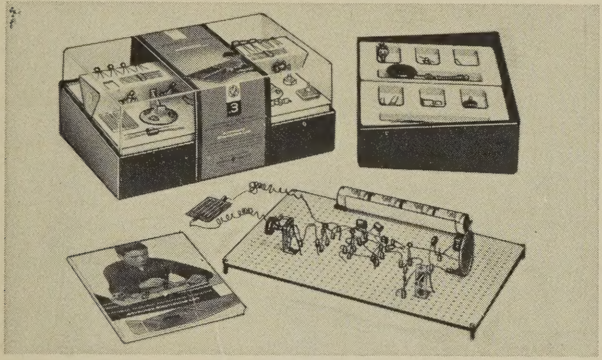
When you have finished with this kit, here are other General Electric Products. All provide fun—plus a further introduction to the world of science and electronics.



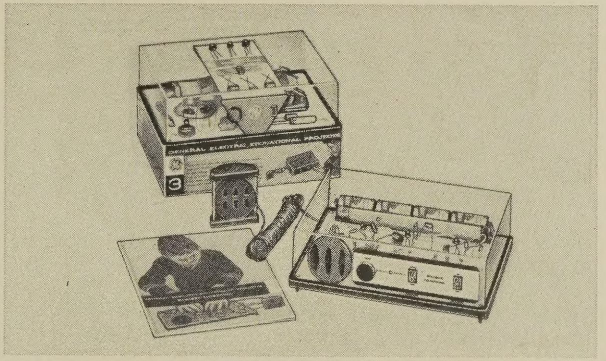
BASIC TRANSISTOR LAB. Builds four types of radio receivers, two tuning systems and two experiments in transistor circuits. Teaches fundamentals of transistors and diode radio.



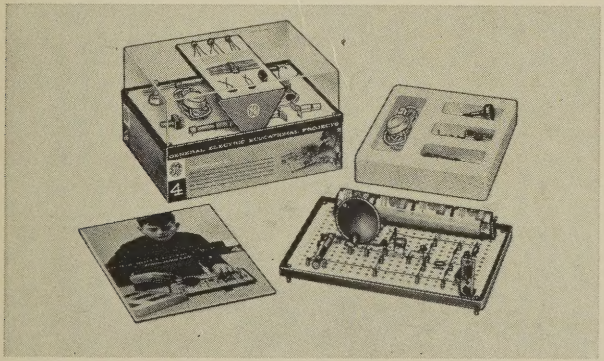
PROJECT 2: TRANSMITTER. Builds a 3-transistor transmitter. Broadcasts can be received on any closeby standard home radio. Basic principles of radio transmission taught.



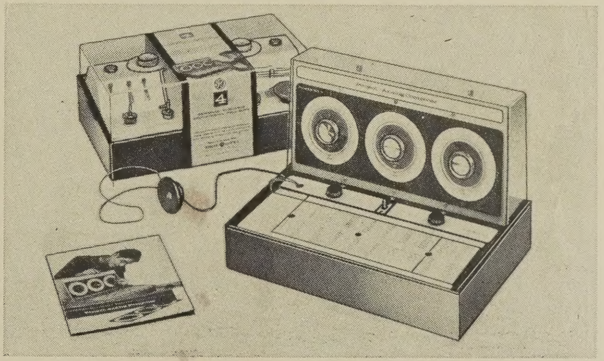
ADVANCED ELECTRONICS LAB. Over 50 elementary and advanced experiments in electronics. Build seven types of radio receivers, two of transmitters, public address system.



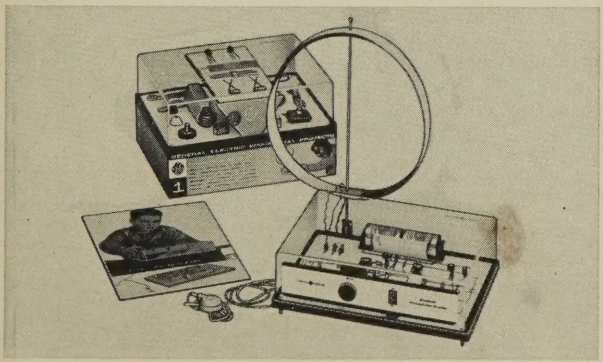
PROJECT 3: INTERCOM. Build and talk over a 3-transistor intercom. Finished master and remote stations operate over distances limited only by the length of connecting wires.



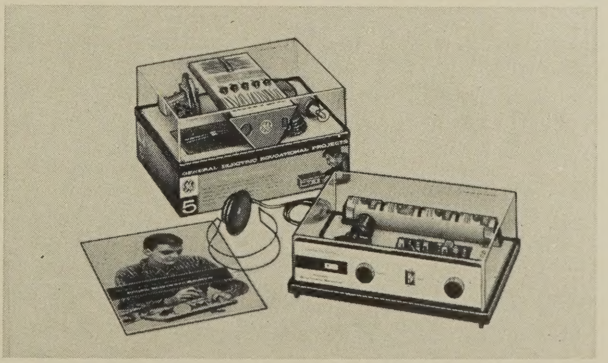
ELECTRONICS LAB. Offers intermediate lab work with more than 30 experiments. Constructs transistor amplifiers, oscillators, receivers, transmitters and alarm systems.



PROJECT 4: ANALOG COMPUTER. Teaches electronics and mathematics. Memory panels and accurate audio indicator with 3-transistor amplifier aid in working on problems.



PROJECT 1: TRANSISTOR RADIO. Enables construction of a self-contained radio receiver based on the transistor. Receiver has built-in air loop antenna.



PROJECT 5: SHORTWAVE RADIO. Standard shortwave radio that receives international, amateur, and police broadcasts. Has beat frequency oscillator for code reception. Soldering iron included, parts to be soldered to printed circuit board.

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